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Cyclopedia
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Applied Electricity

A General Reference Work
ON DYNAMO-ELECTRIC MACHINERY, GENERATORS, MOTORS, STORAGE
BATTERIES, ELECTRIC WIRING, ELECTRICAL MEASUREMENTS,
ELECTRIC LIGHTING, ELECTRIC RAILWAYS, POWER
STATIONS, POWER TRANSMISSION, ALTERNATING CURRENT MACHINERY, TELEPHONY, TELEGRAPHY, ETC.

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THE editors have freely consulted the standard technical literature of America and Europe in the preparation of these volumes. They desire to express their indebtedness, particularly to the following eminent authorities, whose well-known works should be in the library of every electrician and engineer.

Grateful acknowledgment is here made also for the invaluable co-operation of the foremost engineering firms and manufacturers in making these volumes thoroughly representative of the very best and latest practice in the design, construction, and operation of electrical machinery and instruments; also for the valuable drawings, data, suggestions, criticisms, and other courtesies.

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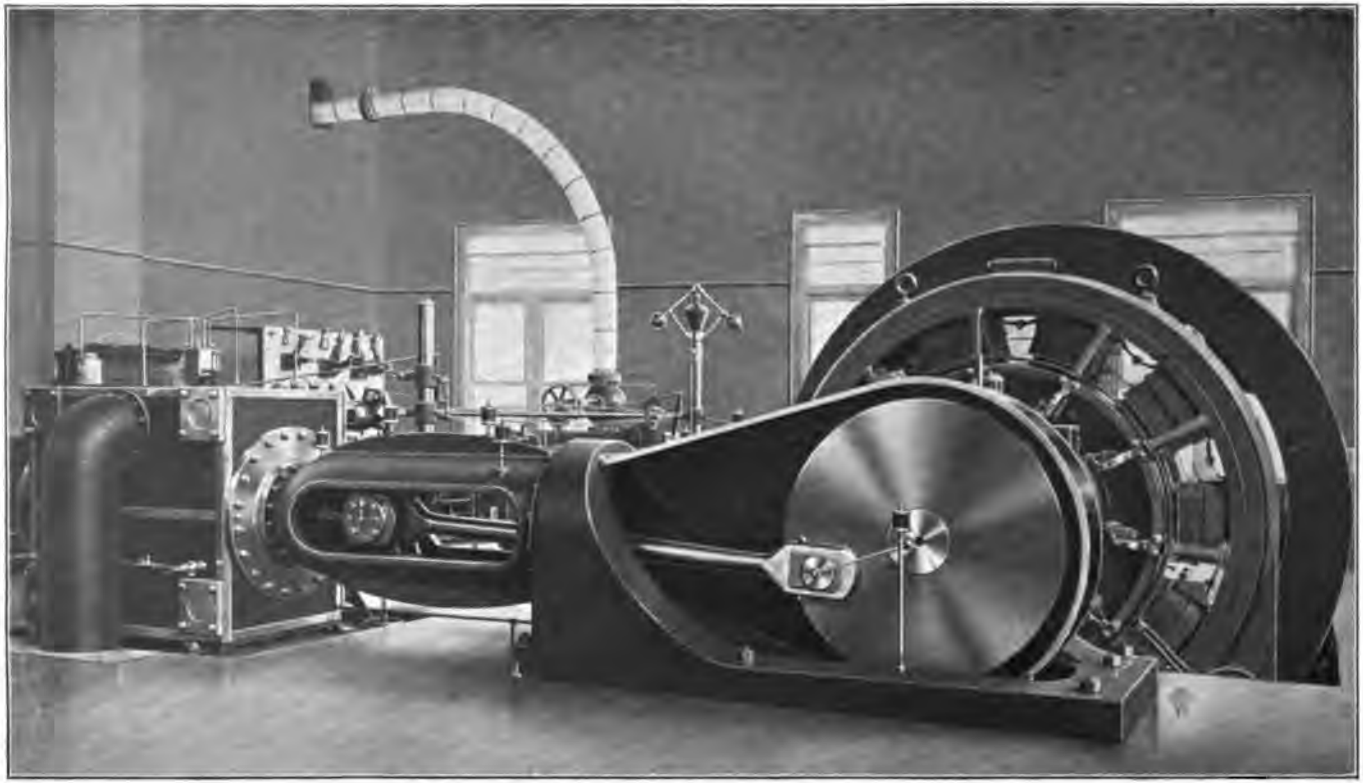

DIRECT-CURRENT VERTICALLY SPLIT GENERATOR DIRECT CONNECTED TO CROSS-COMPOUND HAMILTON-CORLISS ENGINE

Fort Wayne Electric Works

Foreword

IN view of the great need for a more scientific knowledge of electricity on the part of thousands of practical men of limited technical education, an attempt has been made in the following pages to give a presentation of the subject which shall be easily understood by such men, and at the same time cover all essential principles and methods. The principles usually deduced by higher mathematics are here made clear by careful explanation and a large number of diagrams drawn especially to supplement and elucidate the text. Numerous engravings exemplify modern practice, and form a pictorial index to the latest and best methods of applying electricity to lighting, railways, power transmission, the driving of machine tools, etc.

¶ The Cyclopedia of Applied Electricity is based upon the method which the American School of Correspondence has developed and successfully used for many years in teaching practical electricians the scientific principles underlying their work. It is a compilation of representative Instruction Papers of the School, and forms a simple, practical, concise, and convenient reference work for the shop, the library, the school, and the home.

¶ The success which the American School of Correspondence has attained in teaching thousands of electricians, is in itself the best possible guarantee for the present work. Therefore, while these volumes are a marked innovation in technical literature—representing as they do the best ideas and methods of a large number of *different* authors, each an acknowledged authority in his work—they are by no means an experiment, but are in fact based on what has proved itself to be the most successful method yet devised for the education of the busy working man.

¶ Among the sections of especial timeliness are those on Alternating-Current Machinery, Storage Batteries, Electric Wiring, Lighting, etc. In these pages the authors have succeeded in presenting the subjects in such manner as to overcome the hitherto insurmountable obstacle—higher mathematics. The rules and formulæ are presented in a very simple manner, and special effort has been made to illustrate every principle by diagrams, curves, and practical examples.

¶ Numerous examples for practice are inserted at intervals; these, with the test questions, help the reader to fix in mind the essential points, thus combining the advantages of a textbook with those of a reference work.

¶ Grateful acknowledgment is due to the corps of authors and collaborators who have prepared the many sections of this work. The hearty co-operation of these men—engineers of wide practical experience, and teachers of acknowledged ability—has alone made these volumes possible.

¶ The Cyclopedia is published in the belief that it will meet a real need among designers, constructors, and operators of electrical machinery. That it may save many weary hours of search among the scattered textbooks and reference works of the day—books which, being intended largely for college-trained men, are necessarily far from meeting the needs of the average practical man—is the hope of the compilers and publishers.

Table of Contents

VOLUME IV

MANAGEMENT OF DYNAMOS AND MOTORS . *By F. B. Crocker*† Page *11

Selection of Machine—Location and Erection—Direct Connection—Belt and Rope Driving—D. C. and A. C. Plants—Parallel and Series Connections—Constant-Potential D. C. Circuits—Shunt, Series, Differentials, and Compound Winding—A. C. Motors—Induction Motors—Compensators—Speed Regulation—Rules for Operation—Inspection and Testing—Measuring Instruments—Locating and Remedying Troubles

POWER STATIONS . . . . *By G. C. Shaad* Page 127

Location—Choice of Generating and Transmission Systems—Advantages of Concentrating Plant—Steam and Hydraulic Plants—Steam Engines and Turbines—Water Turbines—Pelton Wheel—Generators—Transformers—Storage Batteries—Switchboards—Standard Wire and Cable—Panels—Ammeters—Voltmeters—Rheostats—Circuit-Breakers—Lightning Arresters—Speed-Limit Devices—Layout of Station—Office Management

CENTRAL STATION ENGINEERING . . *By R. F. Schuchardt* Page 205

Development of Central Station Idea—Brush Arc System—Edison Constant-Potential System—Three-Wire D. C. System—The Edison Companies—A. C. Systems—Development of Water Powers—Functions of Storage Battery—Consolidation of Plants—High-Voltage Polyphase Systems—Central Station Design

STORAGE BATTERIES . . . . . . *By F. B. Crocker* Page 259

Primary and Secondary Cells—Electrolyte and Chemical Action—Fundamental Types of Batteries (Planté, Faure)—Commercial Types (Gould, Bijur, E. P. S., Exide, Chloride, Edison, etc.)—Charging, Discharging—Efficiency—Depreciation—Troubles and Remedies (Sulphating, Buckling, Disintegrating, Sedimentation, Short-Circuiting, Acid Spray)—Testing Electrolyte—Putting out of Commission—Commercial Applications—Portable Batteries—Regulation

POWER TRANSMISSION . . . . . . *By G. C. Shaad* Page 327

Conductors—Temperature Coefficient—Resistance—Current-Carrying Capacity—Insulation—Annunciator Wire—Underwriters' Wire—Weatherproof Wire—Gutta-percha and India Rubber—Distribution Systems—Feeders and Mains—Series-Multiple and Multiple-Series Systems—Multiple-Wire Systems—Voltage Regulation—A. C. Systems—Wiring Formulæ—Transformers—Efficiency—Regulation—Overhead Lines—Underground Lines

REVIEW QUESTIONS . . . . Page 399

INDEX . . . . Page 411

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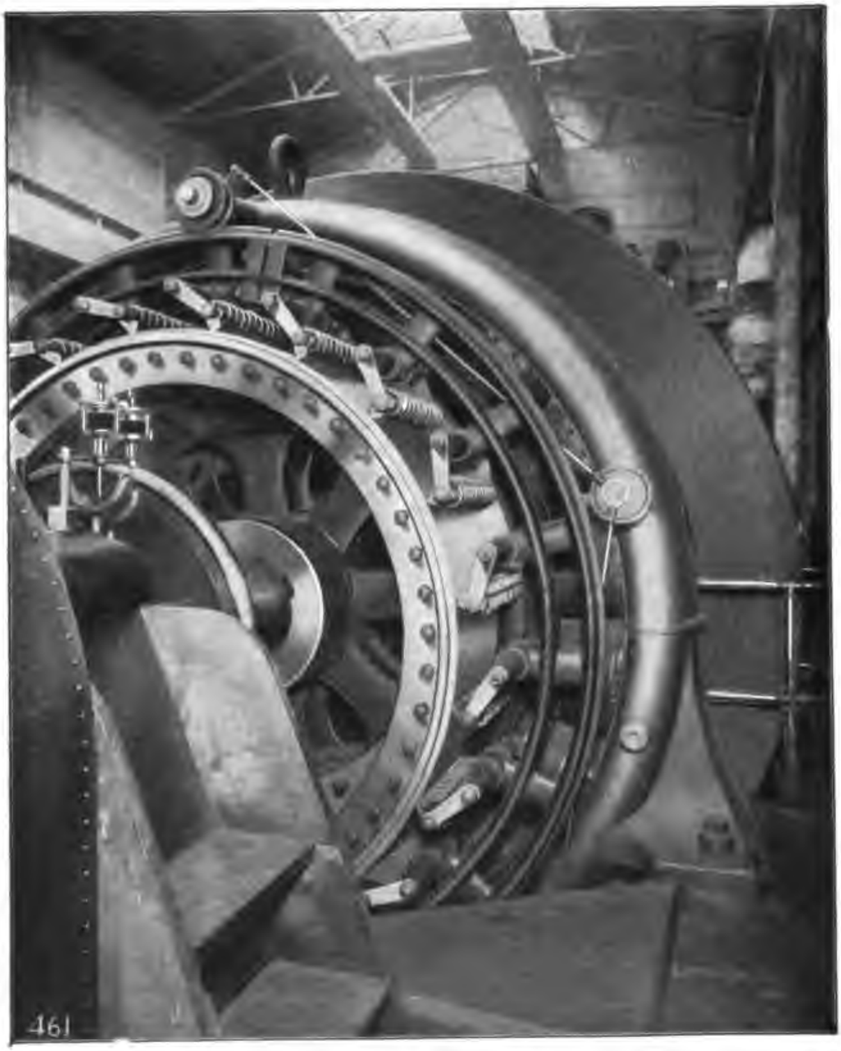
*For page numbers, see foot of pages.

†For professional standing of authors, see list of Authors and Collaborators at front of volume.



800 K. W. ENGINE-TYPE GENERATOR, DIRECT CURRENT

Bullock Electric Manufacturing Co.

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

The object of this instruction paper is to set forth the most important features which must be considered in the actual handling and operation of electric generators and motors. The principles and general construction of direct-current (D. C.) and alternating-current (A. C.) generators and motors, are treated elsewhere.

The subject may be divided into three parts as follows:

A. The Selection, Erection, Connection, and Operation.
B. The Inspection and Testing.
C. The Troubles or "Diseases" and Remedies.

SELECTION OF A MACHINE.

The voltage, capacity, and type of machine are dependent upon the system to which it is to be connected, and the purpose for which it is to be utilized, but there are certain general features which should be considered in every case.

Construction. This should be of the most solid character and guaranteed first-class in every respect, including materials and workmanship.

Finish. A good finish is desirable, since it is likely to cause the attendant to take greater care of the equipment.

Simplicity. The machine should be as simple as possible in all its parts; peculiar or complicated features should be avoided, unless absolutely essential for the operation of the system.

Attention. The amount of attention required by the machine should be small. The number of screws or nuts should be reduced to a minimum, and they ought always to be provided with some locking device to prevent them from becoming loose. The brushes should be capable of being easily adjusted and self-feeding, so that they may "follow" or make up for any trifling eccentricity of the commutator. The bearings should be self-oiling, and in the smaller sizes self-aligning.

Handling. An eye-bolt or other means by which the machine can be easily lifted and moved is desirable. It ought to be possible to take out the armature conveniently by removing one of the bearings, or the tops of the field magnet, frame and bearings, or by moving the halves sideways if the frame is split vertically. The armature and field windings should be so designed and mounted that their removal for repairs is an easy matter.

Interchangeability. The machine selected should preferably be one of a regular and standard type, so that extra parts can be obtained without needless delay.

Regulation. Some form of regulating device should be provided by means of which the E. M. F. or current of a generator, or the speed, and in some cases the direction of rotation of a motor, can be readily and accurately controlled.

Form. The machine should be symmetrical, well-proportioned, compact and solid in form. The large and heavy portions should be placed as low as possible, to give greater stability.

Weight. It is a mistake to select a very light machine when it is for stationary use, since weight increases its strength, stability, and durability.

Capacity. This should be ample for the work to be done; in fact it is advisable to allow a margin for increase. The machine should be provided with the maker's name-plate, specifying the rated current, voltage, speed and capacity. The manufacturer should also guarantee the following: That the machine does not heat up in any part of its windings, to more than 50° C, after a run of six hours' duration, under rated load conditions;* also that it is able to carry a 25 per cent overload for two hours, and momentary overloads of 50 per cent, without excessive heating or sparking.

Cost. It is usually an error to select a generator or motor simply because it is cheap, since both the materials and workmanship required for the construction of a high-grade electrical machine are costly.

MECHANICAL CONDITIONS.

Location. The place chosen for the machine should be *dry, free from dust or grit, light, and well ventilated.* It must also be arranged so that there is room enough for the removal of the armature without shifting or turning the machine.

Foundations. It is of great importance to have the machine firmly placed upon a good and solid foundation; otherwise, no matter how well constructed and managed, the vibrations occurring on a poor foundation will produce sparking at the brushes, and its accompanying troubles.

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*Note. By resistance measurements.

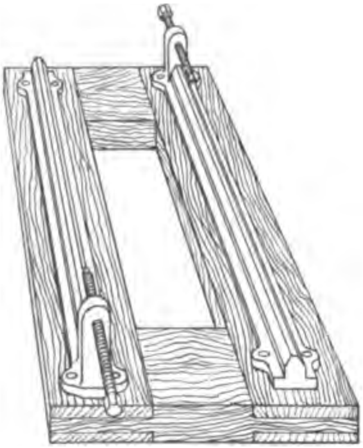

Fig. 1.

It is also necessary, if the machine is belt-driven, to mount it upon rails or a sliding bed-plate provided with holding-down bolts and tightening screws for aligning and adjusting the belt while the machine is in operation. (See Fig. 1). The machinery foundations consist of a mass of stone, masonry, brickwork, or concrete, upon which the machinery is placed and usually held firmly in place by bolts passing entirely through the mass. These bolts are built into the foundations, the proper position for them being determined by a wooden template suspended above the foundation, as shown in Fig,·2. The bolts are preferably surrounded by iron pipe that fixes them longitudinally but allows a little side play which may be necessary to enable them to enter the bed-plate

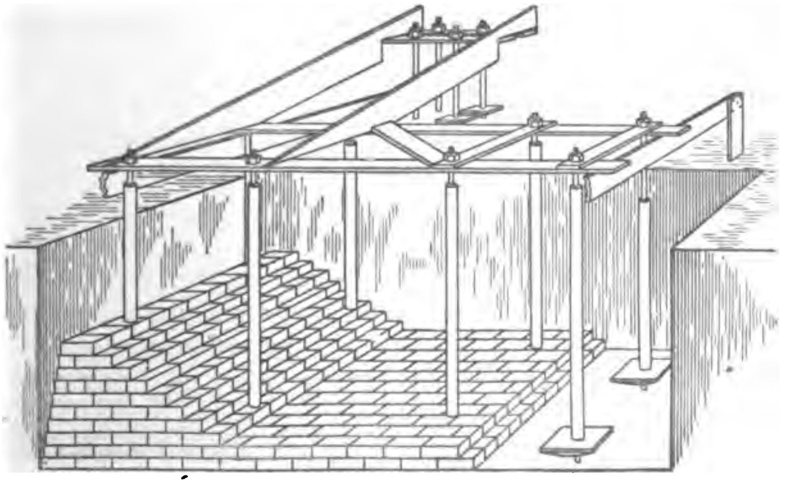

Fig. 2.

holes readily. The brickwork for machinery foundations should consist of hard burned bricks of first quality, *laid in good cement mortar.* Ordinary *lime mortar is entirely unfit* for the purpose, being likely to crumble away under the effect of the vibrations caused by the machinery. Brick or concrete foundations should be finished with a cap of bluestone or cement. This tends to hold the foundation together, and forms a level surface upon which to set the machinery. If the engine and generator are provided with a cast-iron sub-base, the capping may be dispensed with

Fixing the Machine. In fixing either direct-connected or belt-driven machines, first determine, with a long straight edge and spirit level, if the top of the foundation is level and true. If this is found to be the case, the holding-down bolts may be dropped into the holes in the foundation, if they are not already built in, and the machine carefully placed thereon, the ends of the bolts being passed through the holes in the bed-plate and secured by a few turns of the nuts. The machine should then, if belt-connected, be carefully aligned with the transmitting pulley or fly wheel. Particular attention should be paid to the alignment of the pulleys in order that the belt may run properly. If direct-connected, the dynamo bed-plate and armature shaft must be carefully aligned and adjusted with respect to the engine shaft, raising or lowering the bed-plates of the corresponding machines by means of thin cast-iron or other wedges; and the generator frame should also be adjusted to its proper height by means of thin strips of metal or fiber set between its supporting feet and the bed-plate. Having thus aligned and leveled the machine, it should next be grouted with thin cement. This is done by arranging a wall of mud or wooden battens around the bed-plates of the machines, and running in thin cement until the holding-down bolt holes are filled, and the cement has risen to the level of the under side of the bed-plate. When the cement has set, the wall may be removed and the nuts on the holding-down bolts drawn up. This firmly fixes the machine upon its foundation.

Mechanical Connections. Various means are employed to connect the engine or other prime mover with the generator, or the motor with the apparatus to be driven. The most important are as follows:

Direct Connection.
Belting.
Rope Driving.
Toothed Gearing.

Other apparatus, such as shafting, clutches, hangers and pulleys, are used in connection with the above means.

Direct Connection. This is the simplest, and for that reason the most desirable, means of connection, provided it can be carried out without involving sacrifices that offset its advantages. This method, also called direct coupling or direct driving, compels the engine and generator to run at the same speed, which gives rise to some difficulty, as the most desirable speeds of the two machines do not usually agree. The natural speed of a generator is high, while that of an engine is low; hence to obtain the same voltage from a direct-connected generator, more inductors are necessary, or the flux cut must be increased. Accordingly, the armature and frame of the direct-connected generator must be larger, thus making it a more expensive machine than the belt-driven.

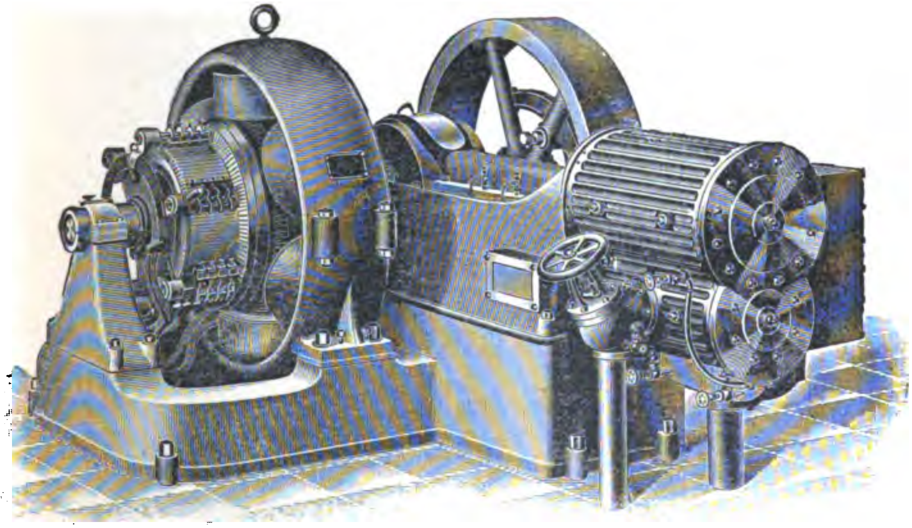

Fig. 3.

The direct connection of an engine and generator is accomplished in several ways; the simplest of which consists in mounting the armature of the generator directly on one end of the shaft of the engine. This may be accomplished in any one of several ways. Fig. 3 represents the three-bearing method. Two-and-four-bearing methods are also used. These secures the great advantages: that accurate alignment is readily obtained, and space occupied reduced to a minimum, and the mounting of the bearings on a common sub-base avoids trouble due to unequal settling.

Another form of direct coupling is that in which an engine and a generator, each complete in itself, and each having two bearings, are coupled together by some mechanical device, which may be either rigid or slightly elastic or adjustable. In the former case the two shafts are practically equivalent to a single one, which, while making it easy to remove either machine for repairs, is somewhat objectionable owing to the fact that it requires larger foundations, and introduces the difficulty of accurately aligning four bearings. The use of a flexible coupling avoids the necessity of perfect alignment, and also the serious trouble that might arise if the settling or the wear of the bearings should be uneven. There are various forms of flexible coupling. One of the forms manufactured by the Westinghouse Machine Company is shown in Fig. 4, the flexibility being provided by the springs which hold the two parts of the coupling together.

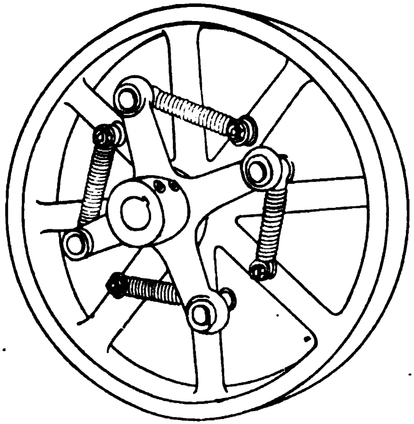

Fig. 4.

The direct coupling of generators with turbines can be carried out without departing from the natural speed of either machine, since the ordinary speed of a turbine agrees closely with the normal speed of a generator of the corresponding capacity.

The relative efficiency of direct coupling and belting depends greatly upon the conditions; but in general the former is more efficient at or near rated load, and the latter at light loads. *The simplicity, compactness, and positive and noiseless action of direct connection* have caused it to become the most approved method.

Belting. If the generator or motor is not directly connected, one to the prime mover and the other to the apparatus to be driven, they are usually connected by some form of belting. The kind of belting selected depends greatly upon conditions of drive, distances, etc.; and it may be leather, rawhide, rubber, or rope. For ordinary short drives, leather is the most desirable, though, when the power to be transmitted is small, rawhide belts are also satisfactory, especially as the cost is less than for leather belts. For considerable distances, rope driving answers very well because it is so much lighter and cheaper than an equivalent leather belt, though grooved pulleys are required, making the total cost about the same. Rubber belts are used to advantage in driving generators from water turbines, where the belt might be exposed to moisture. Leather belting is usually the most reliable and satisfactory for general application, except for very short drives, where a form of chain belt works best. There are three thicknesses of leather belting—single, light-double, and double. For use in connection with generators, motors, or other high-speed machinery, the "light-double" belting is usually the best.

The exact amount of power that a given belt is capable of transmitting is not very definite. The ordinary rule is that "single" belt will transmit 1 horse-power for each inch of its width when traveling at a speed of 1,000 feet per minute. If the speed is greater or less, the power is proportionately increased or decreased. The statement of H. P. transmitted is based upon the condition that the belt is in contact with the transmitting pulley around one-half of its circumference, or 180°, which is usually the case. If the arc of contact is less than 180°, the power transmitted is less in the following proportion: An arc of 135° gives 84 per cent, while 90° contact gives only 64 per cent of the power derived from a belt contact of 180°. If on the other hand, the upper side sags downward, which is always desirable, the belt is in contact with more than half the circumference of the pulley; and thus the grip is considerably increased and more power can be transmitted. These facts make it very desirable to have the *loose side of the belt on top*. If the loose side is below, it sags away from the pulley and is also likely to strike the floor.

The complete expression for determining the width of a single belt required to transmit a given horse-power is as follows:

$$W = \frac{H.\,P. \times 1{,}000}{S \times C},$$

where W is the width of the belt in inches; H. P. the horse-power to be transmitted; S the speed of the belt in feet per minute, which is equal to the circumference of the driving pulley in feet multiplied by the number of revolutions per minute;* and C a factor dependent upon the arc of contact.

"Double" belting is expected to transmit one and one-half ($1\frac{1}{2}$), and "light-double" one and one-quarter ($1\frac{1}{4}$) times as much power as "single" belting of the same width. Belting formulas are only approximate, and should not be applied too rigidly, since the grip of the belt upon the pulley varies considerably under different conditions of tension, temperature and moisture. The smooth side of a belt should always be run against the pulley, as it transmits more power and is more durable. Belting used for electric machinery, being usually high-speed, should be made "endless" for permanent work, as this makes less noise; but it may be used with laced joints, temporarily. A spliced or "endless" joint is made as follows:—Both ends of the belt are pared down on one side (opposite) with a sharp knife, into the form of a long thin wedge, so that when laid together a long uniform joint is obtained of the *same thickness as the belt itself.* The parts are then firmly joined with cement and sometimes with rivets also. It may be necessary to splice or lace a belt while in position on the pulleys; and for this purpose some form of belt clamp (Fig. 5) should be employed.

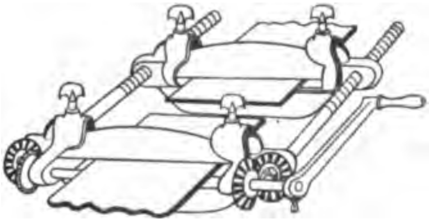

Fig. 5.

If a belt is ordered endless, or is spliced away from the pulleys, great care should be exercised in determining the exact length required. A string that will not stretch, or preferably a wire put around the pulleys in the position to be occupied by the belt, is the best way to avoid a mistake. In measuring for a belt, the generator or motor should be moved on its sliding base so as to make the distance between shaft centers a minimum, in order to allow for the stretch of the belt, which may be as much as ½ inch per foot of length.

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* NOTE. Belts slip or "creep" on the pulley about 2 per cent; hence, in determining the size of pulleys whose speed must be accurate, the calculated belt speed should be about 2 per cent too high.

The lacing of a belt is a very simple and common method of making a joint; but should not be permanently employed at high speeds for electric machinery belting, as it is liable to pound on the pulleys, producing noise, vibration and sparking; and in the case of generators it is also likely to cause flickering in the lamps. In lacing belts, the ends should be cut *perfectly square, and there should be as many stitches of the lace slanting to the left as there are to the right;* otherwise the ends of the belt will shift sidewise owing to the unequal strain, and the projecting corners may strike or catch in the clothing of persons. A good way to accomplish this is shown in Fig. 6. The various holes should be made with a circular punch, the nearest one being about ¾ inch from the side, and the line through the center of the row of holes about 1 inch from the end of the belt. In large belts these distances should be a little greater. A regular belt lacing of strong pliable leather or a special wire is used. The lacing is doubled to find its middle; and the two ends are passed through the two holes marked "*1*" and "*1a*," precisely as in lacing a shoe. The two ends are then passed successively through the two series of holes, in the order in which they are numbered, *2*, *3*, *4*, etc., and *2a*, *3a*, *4a*, etc., finishing at *13* and *13a*, which are additional holes for securing the ends of the lace. The great advantage of this method of lacing is that the lace lies on the pulley side perfectly parallel to the direction of motion.

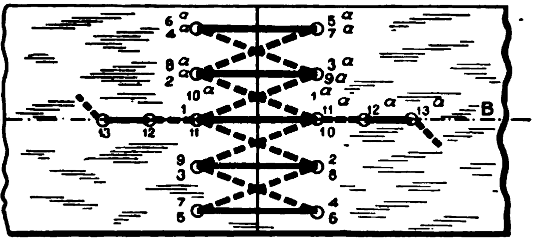


Fig. 6.

Perforated belts are often employed for the reason that a film of air is likely to be imprisoned between the belt and the pulley, thus preventing a good grip. Hence small perforations are sometimes made in the belt, especially for high-speed operation (3,000-5,000 feet per minute), to allow the air to escape; and since these are in the form of narrow slits, with their greatest dimension in the direction of motion, they do not materially reduce the strength of the belt.

Arrangement and Care of Belting. It is very desirable, for satisfactory running, that belts should be reasonably long and nearly horizontal. The distance between the centers of two belt-connected pulleys should be not less than 3 times the diameter of the larger pulley. The belt should be just tight enough to avoid slipping, without straining the shaft or bearings. The two shafts which are to be belt-connected must be perfectly parallel, and the centers of the face of the driving and driven pulleys must be exactly opposite to each other, in a straight line perpendicular to the axis of the shafts. The machines should then be turned over slowly with the belt on, to see if the latter tends to run to one side of the pulley, which would show that it is not yet properly "lined up," in which case one or both machines should be slightly shifted, until the belt runs properly. If possible, the machine and belt should be set and adjusted so as to cause the armature to move back and forth in the bearings while running, on account of the side motion of the belt, and thus make the commutator wear more smoothly, and distribute the oil in the bearings.

It is always desirable to have belts as pliable as possible; hence the occasional use of a good belt dressing—as neatsfoot oil, etc.—is recommended. Rosin and other sticky substances are sometimes applied to increase the adhesion; but this is a practice allowable only in an emergency, as it may destroy the belt surface.

In places where the belting is very much exposed, and liable to catch in the clothing of any person, it is advisable to surround it by a railing or box.

Rope Driving possesses advantages over ordinary belting in some cases. The rope runs in V-shaped grooves in the peripheries of the pulleys, and thereby obtains a great grip by a sort of wedging action. The kinds of rope ordinarily employed for this purpose are cotton, hemp, rawhide and wire. The general advantages are:

1. Economy in cost.

2. Large amount of power that can be transmitted with a given diameter and width of pulley, on account of the grip obtained.

3. It is almost noiseless.

4. Ropes, on account of their lightness, can be used to transmit power over greater distances than are possible with any other form of belting; and also for very short distances on account of the wedging action. Manila rope is generally used in the United States, being of three strands, hawser laid, and may be from ½ inch to 2 inches in diameter. The breaking strength varies from 7,000 to 12,000 pounds per square inch of cross-section. It has been found that the best results are obtained when the tension in the driving side of the rope is only 3 to 4 per cent of the breaking strength.

The diameter of a single rope necessary to transmit a required H. P. is given by the formula:

$$D^2 = \frac{825 \text{ H.P.}}{V\left(200 - \frac{V^2}{1,072}\right)},$$

in which H. P. = horse-power transmitted;
V = velocity of rope in feet per second;
D = diameter of rope in inches.

The maximum power is obtained at a speed of about 84 feet per second. With higher speeds the centrifugal force becomes so great that the power transmitted decreases rapidly, and at about 142 feet per second it counteracts the whole allowable tension (200 D^2 pounds) and no power is transmitted.

Arrangement of Rope Belting. There are two methods of arranging rope transmission: one consists in using several separate belts; and the other employs a single endless rope which passes spirally around the pulley several times and is brought back to the first groove by a slanting idle pulley, and therefore is called the "wound" system. The separate ropes do not require the carrying-over pulley, and if one rope breaks, those remaining are sufficient to transmit the power temporarily; whereas an accident with the single-rope system entirely interrupts the service. In the "multi-rope" system it is practically impossible to make and maintain the belts of exactly equal length, hence the tensions on the various ropes differ, and they hang at different heights on the slack side, producing an awkward appearance.

Toothed Gearing possesses the decided advantages of positive action and the ability to give large ratios of speed and small side pressure on the bearings. Nevertheless it is seldom employed for driving generators. As the most extensive applications of gearing for electrical purposes are in connection with railway motors, it will be taken up under that heading.

SHAFTING.

An intermediate or counter shaft is not desirable since it increases the complication and frictional losses of the system; but it is often necessary in the generation or application of electric power, either to obtain a greater multiplication of speed than is possible by belting directly, or to enable a single engine or motor to drive a greater number of machines.

The two important kinds of shaftings are "cold-rolled" and "turned." The former is rolled to the exact size and requires no further treatment. It has the advantage of a smooth, hard surface, but it is difficult to make perfectly true and straight. Turned-steel shafting is most commonly employed, and has the advantage that shoulders, journals, or other variations in size can be easily made on it. The following table gives the ordinary data for shafting:

TABLE I.

Shafting.

Diameter in inches.	Weight lbs. per ft.	Allowable H. P. transmitted at 100 r. p. m.	Width of key seat in inches.
$1\frac{7}{16}$	5.5	4.3	$\frac{3}{8}$
$1\frac{15}{16}$	10.	10.	$\frac{1}{2}$
$2\frac{7}{16}$	15.8	20.	$\frac{3}{4}$
$2\frac{15}{16}$	23.	34.	$\frac{3}{4}$
$3\frac{7}{16}$	31.5	54.	$\frac{7}{8}$
$3\frac{15}{16}$	41.	80.	1
$4\frac{7}{8}$	62.8	156.	1
$5\frac{7}{8}$	91.1	270.	1

With speeds greater than 100 r. p. m., the allowable H. P. varies directly in proportion to the speed employed.

ASSEMBLING OF THE MACHINE.

In unpacking and putting the machine together, great care should be used to avoid the least injury to any part, to clean scrupulously each part, and to put the parts together in exactly the right way. This care is particularly important with regard to the shaft, bearings, magnetic joints, and electrical connections, from which every particle of grit, dust, metal chips, waste, etc., should be removed. It is advisable to study carefully the blue prints or instruction matter usually sent with each machine, before attempting to put it together. The armature must be handled with great care in order not to injure the wires and their insulation as well as the commutator and shaft. The armature should be handled as far as possible by the shaft, and when it must be placed on the ground a pad of cloth or layer of boards should be interposed. A convenient form of sling for handling armatures with their shafts in position is shown in Fig. 7. The bearings should be carefully cleaned, set in exactly the right positions, and firmly secured. The tops should be left loose for a short time, so that the tendency to heat up at the first run may be decreased; and after that they

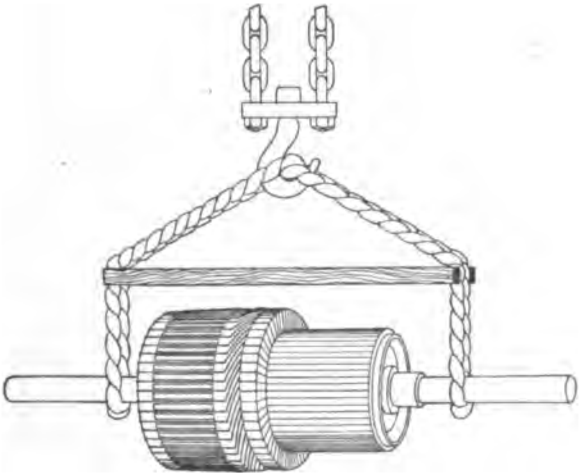


Fig. 7.

should be drawn up tight. The field frame should be set so that the air gap is the same for all pole pieces, as otherwise the machine will be magnetically unbalanced and tend to spark badly.

The adjustment of the brushes, etc., should preferably be left until the machine is electrically connected and ready to receive its trial run.

METHODS OF WIRING.

Before laying the wires, the circuits should be carefully mapped out and the work so planned as to secure the simplest arrangement. The wiring should then be installed neatly and in accordance with the rules of the National Board of Fire Underwriters and of the local department having supervision. Otherwise unnecessary trouble, delay and expense may be incurred.

The wire may be installed in one of two general methods, *viz.:*

Exposed on	Cleats. Knobs. Bushings.
Concealed in	Wooden moulding. Iron conduit. Terra cotta conduit.

The wire should preferably be either rubber-covered or made up in the form of lead cables. Exposed wires possess the advantages of cheapness, as well as accessibility for inspection and repair; and any short circuit or ground is readily seen and removed, whereas it might cause great uncertainty and delay when the wires are concealed.

Concealed conductors, especially where they are placed under the floor, have the great advantage over exposed wiring, in that they are entirely out of the way. This is especially important in large installations, where overhead traveling cranes are almost a necessity.

When alternating-current conductors are enclosed in iron conduits, both wires of each phase, or all the wires, must be run in the same duct, otherwise the inductance would be excessive.

All conductors, including those connecting the machine with the switchboard, as well as the bus bars on the latter, should be of ample size to be free from overheating and excessive loss of voltage. The drop between the generator and switchboard should not exceed $\frac{1}{2}$ per cent at full load, because it interferes with proper regulation and adds to the less easily avoided drop on the distribution system.

The safe carrying capacities of copper conductors as recommended by the Board of Fire Underwriters, are given in the following table:

TABLE II.

Safe Carrying Capacities of Copper Wires.

B. & S. G.	Rubber Insulation. Amperes.	Other Insulations. Amperes.	Circular Mils.
18	3	5	1,624
16	6	8	2,583
14	12	16	4,107
12	17	23	6,530
10	24	32	10,380
8	33	46	16,510
6	46	65	26,250
5	54	77	33,100
4	65	92	41,740
3	76	110	52,630
2	90	131	66,370
1	107	156	83,690
0	127	185	105,500
00	150	220	133,100
000	177	262	167,800
0000	210	312	211,600
Circular Mils.			
200,000	200	300	
300,000	270	400	
400,000	330	500	
500,000	390	590	
600,000	450	680	
700,000	500	760	
800,000	550	840	
900,000	600	920	
1,000,000	650	1,000	
1,100,000	690	1,080	
1,200,000	730	1,150	
1,300,000	770	1,220	
1,400,000	810	1,290	
1,500,000	850	1,360	
1,600,000	890	1,430	
1,700,000	930	1,490	
1,800,000	970	1,550	
1,900,000	1,010	1,610	
2,000,000	1,050	1,670	

The lower limit is specified for rubber-covered wires to prevent gradual deterioration of the high insulations by the heat of the wires, but not from fear of igniting the insulation. The question of drop is not taken into consideration in the above tables.

The carrying capacity of Nos 16 and 18, B & S. gage wire is given, but no smaller than No. 14 is to be used.

The safe carrying capacity of insulated aluminum wire is 84 per cent of that given for copper wires of corresponding size and insulation.

Switches are devices for closing and opening the various circuits or branches of an electrical distribution system. A knife switch should always be employed when the capacity of the circuit to be controlled exceeds 10 amperes. It may be single-, double-, or triple-pole; single- or double-throw; and with or without fuses as desired. If the rated capacity of a switch exceeds 25 amperes, its terminals must be provided with lugs into which the ends of the conducting wires should be soldered. The principal parts of a knife switch (Fig. 8) are the *base* (*a*), which must consist of a non-combustible, non-absorptive insulating material; the *hinges* (*b*), which carry the *blades* (*c*); the contact *jaws* or *clips* (*d*); the insulating *cross-bar* (*e*); and the *handle* (*f*). The hinges, blades and jaws should be made of pure copper, of sufficient cross-section to insure mechanical stiffness and proper carrying capacity, and their contact surfaces must not be less than 1 square inch per 75 amperes of the rating. The hinges and contact jaws must be springy enough to insure good contact with the blades. The blades and jaws must be so shaped that they open along their entire length simultaneously; otherwise the arc which is formed upon opening a loaded circuit will burn off the last points of contact. In fact this arc, when produced by a heavy current, is very difficult to control; and switches should never be opened on heavily-loaded circuits except in an emergency. In practice, however, some form of electro-magnetic circuit-breaker is employed for the purpose, and may be operated automatically with overload, or by hand at any time.

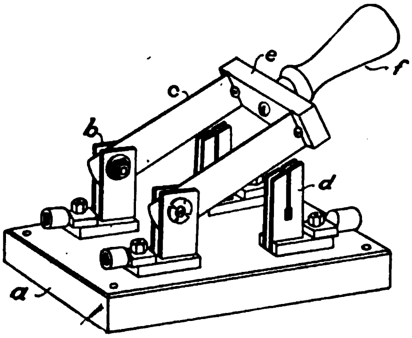
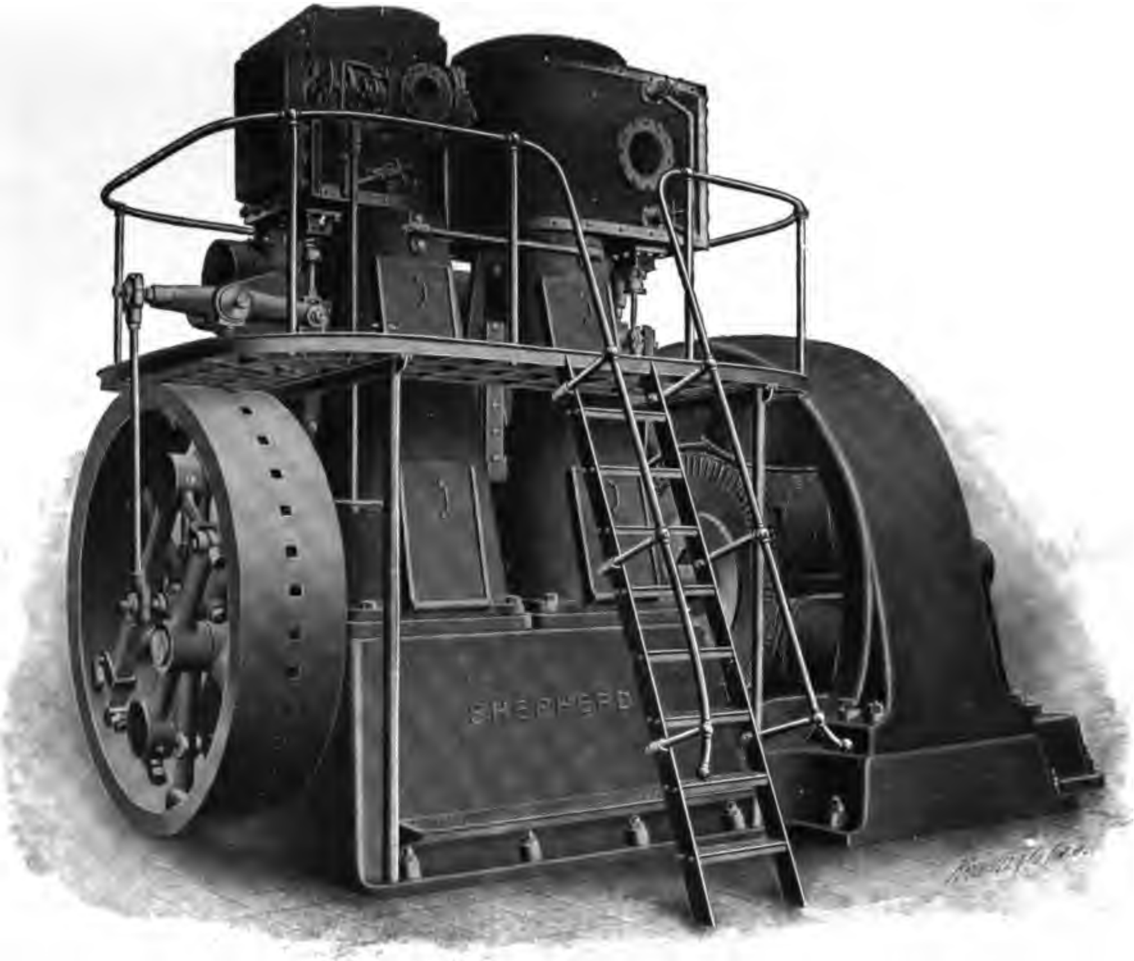


Fig. 8.

Knife switches should be so placed that *gravity tends to open* rather than to close them. They should always be located in dry, accessible places and grouped as far as possible If located in ex-



VERTICAL CROSS-COMPOUND ENGINE DIRECT-CONNECTED TO 400 K.W. DYNAMO.

Shepherd Engineering Company.

posed positions they should be enclosed in slate or equivalently lined cabinets. The distances between the parts of opposite polarity, in an approved knife switch, must never be less than the values given in the following table:

TABLE III.

Switch Data.

125 VOLTS OR LESS:	Minimum Separation of Nearest Metal Parts of Opposite Polarity.	Minimum Break-Distance.
For Switchboards and Panel Boards—		
10 amperes or less	¾ inch	½ inch.
11–25 "	1 "	¾ "
26–50 "	1¼ "	1 "
For Individual Switches—		
10 amperes or less	1 inch	¾ inch.
11– 35 "	1¼ "	1 "
36– 100 "	1½ "	1¼ "
101– 300 "	2¼ "	2 "
301– 600 "	2¾ "	2½ "
601–1,000 "	3 "	2¾ "
126 TO 250 VOLTS:		
For all Switches—		
10 amperes or less	1½ inch	1¼ inch.
11– 35 "	1¾ "	1½ "
36– 100 "	2¼ "	2 "
101– 300 "	2½ "	2¼ "
301– 600 "	2¾ "	2½ "
601–1,000 "	3 "	2¾ "

On switchboards, the above spacings for 250 volts direct current are also approved for 440 volts alternating current. Switches on switchboards with these spacings intended for use on alternating-current systems with voltages above 250, must be stamped with the voltage for which they are designed, followed by the letters "A. C."

251 TO 600 VOLTS:		
For all Switches—		
10 amperes or less	3½ inch	3 inch.
11– 35 "	4 "	3½ "
36–100 "	4½ "	4 "

Auxiliary breaks or the equivalent are recommended for switches designed for over 300 volts and less than 100 amperes, and will be required on switches designed *for use in breaking currents* greater than 100 amperes at a pressure of more than 300 volts.

For three-wire systems switches, must have the break-distance required for circuits of the potential of the outside wires.

Safety Fuses and Cut-outs. Almost all electrical circuits, except those for constant-current arc lighting, are protected from abnormal increase of current by safety fuses. These consist of wires or strips of metal introduced into the circuit, and so designed in cross-section and resistance that they will melt and open the circuit in case of excessive current, before the rest of the system becomes unduly heated.

The requirements for effective safety fuses may be stated as follows:

1. They should melt at a definite current.
2. They should not change in this respect by the effect of time, nor by heating or other action of the current, nor, in fact, under any reasonable conditions.
3. They should act promptly.
4. They should give firm and lasting contacts with the terminals to which they are attached.

These fuses are of two general types:

(*a*) Open or link fuses.
(*b*) Enclosed or cartridge fuses.

The open or link fuses (Fig. 9) consist of strips of fusible alloy provided with copper terminals. Each size is designed to carry a certain normal current, but will melt and open the circuit when the current exceeds that rating by 25 per cent. When a link fuse "blows" as a result of overloading, the rupture is accompanied by a flash, and by spattering of the fused material. With large currents this phenomenon is a source of danger, and the use of enclosed fuses is accordingly recommended whenever the rating of the fuse exceeds 25 amperes.

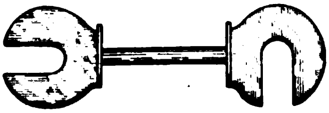


Fig. 9.

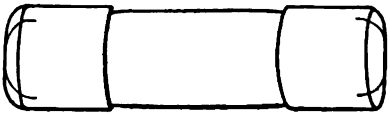


Fig. 10.

Enclosed fuses (Fig. 10) have a casing around the fusible material, which prevents the dangerous spattering and which also smothers the arc that tends to form whenever a fuse blows.

Fuses should always be employed when the size of the wire changes, or where connections between any electrical apparatus and the conductors are made. They must be mounted on slate, marble, or porcelain bases; and all metallic fittings employed in making electrical contacts must have sufficient cross-section to insure mechanical stiffness and carrying capacity.

Electro-magnetic Circuit-Breakers or **Limit Switches** are frequently used in place of fuses to protect electrical circuits. Their general construction and application are indicated in Fig. 11. The current is led through a helix A the electro-magnetic action of which, when the current reaches a predetermined limit, automatically releases the blades from contact with the jaws and thus opens the circuit. The final break occurs at carbon tips, thus preventing destructive arcing at the copper contacts. Circuit-breakers possess the following advantages over fuses:

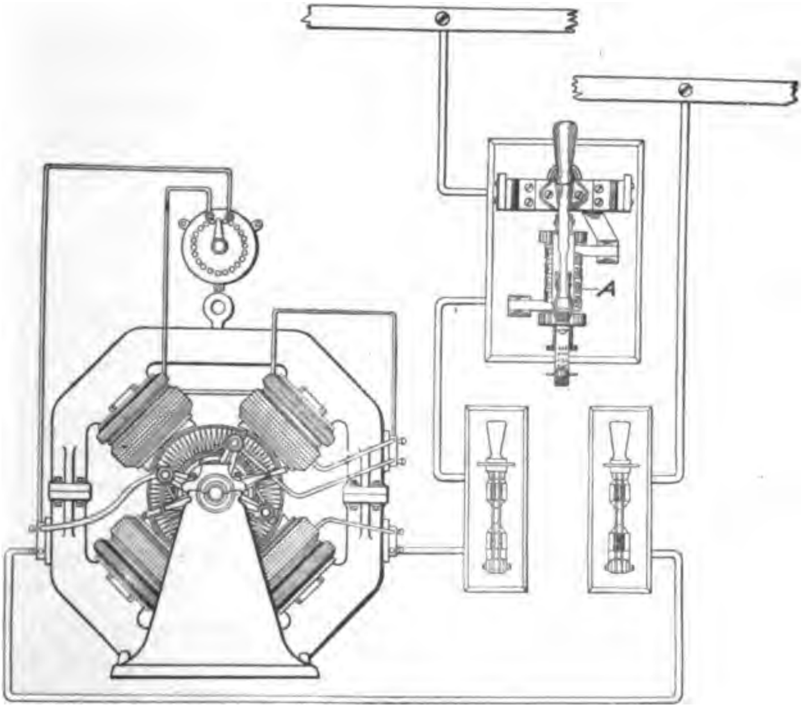


Fig. 11.

1. They can be employed as switches if desired.

2. They can easily be reset and thus put into condition for acting again.

3. Their range can be easily varied within considerable limits.

4. They can also be made to operate "tell tales" whenever the circuit they control is opened.

On account of these general advantages, their use is advisable on switchboards of systems that are liable to frequent overloads. The circuits, however, should, as a rule, be provided also with fuses, since it is possible that the circuit-breaker may fail to open, owing to corrosion or other cause.

Starting-Boxes should always be furnished with D. C. motors, for the following reason: If the line voltage should be applied directly to the terminals of the armature while it is standing still, a very excessive current would flow, since the resistance is low and no C. E. M. F. exists. Hence, to prevent injury to the winding, a resistance is inserted between one supply terminal and the armature in order to reduce the electromotive force at the motor terminals while it is speeding up, the resistance being gradually reduced until completely removed when rated speed is reached. All motor starting-boxes must also be provided with a **no-voltage release.** This consists of an electro-magnet in series with the shunt-field circuit, which holds the rheostat arm in the operating position as long as current flows through the shunt field from the line. If the line switch be opened or the shunt-field circuit accidentally broken, the device becomes demagnetized and releases the arm, which returns to its starting position (all resistance in circuit) by the action of a spring or of gravity. The starting-boxes of larger motors are also frequently equipped with **overload releases.** These, practically, are electro-magnetic circuit-breakers which open the supply lines if the motor becomes greatly overloaded. The general arrangement of switches, cut-outs and starting-boxes should be in accordance with the following extract from the Rules of the National Board of Fire Underwriters:

"Each motor and starting-box must be protected by a cut-out and controlled by a switch, said switch plainly indicating whether 'on' or 'off.' The switch and rheostat must be located within sight of the motor, except in cases where special permission to locate them elsewhere is given, in writing, by the Inspection Department having jurisdiction.

"Where the circuit-breaking device on the motor-starting rheostat disconnects all wires of the circuit, this switch may be omitted.

"Overload-release devices on motor-starting rheostats will not be considered to take the place of the cut-out required if they are inoperative during the starting of the motor.

"The switch is necessary for entirely disconnecting the motor when not in use; and the cut-out, to protect the motor from excessive currents due to accidents or careless handling when starting. An automatic circuit-breaker disconnecting all wires of the circuit, may, however, serve as both switch and cut-out."

The **Various Kinds of Circuit** on which motors and generators are commonly used, and the best type of machine in each case, are as follows:

TABLE IV.

Types of Machine for Various Kinds of Circuits.

DIRECT-CURRENT, CONSTANT-POTENTIAL.

Circuits on which potential or voltage is kept constant; machines, lamps, etc., being run in parallel.

Currents intended for—	Potential.	Generator should be—	Motor should be—
Electro-metallurgy.	1 to 150 volts	Shunt-wound.	Not used.
Incandescent lighting.	110 to 125 volts (2-wire sys.) 220 to 250 volts (2- or 3-wire sys.)	Shunt- or compound-wound.	Shunt-wound for constant speed. Sometimes series- or compound-wound for variable speed.
Electric railway Electric power.	500 to 660 volts	Compound-wound.	Series-wound for railway. Shunt-wound for stationary.

DIRECT, CONSTANT-CURRENT.

Circuits on which current or amperes are kept constant; machines, lamps, etc., being run in series.

Circuits intended for—	Current in Amperes.	Generator should be—	Motor.
Arc lighting.	6.8 or 9.6	Series-wound with current regulator.	No longer used.

ALTERNATING-CURRENT, POLYPHASE.

Constant-potential, two- or three-phase currents.

Circuits intended for—	Potential in Volts.		Generator should be—	Motor is—
Power transmission.	On the line, 5,000 to 60,000.	In the machines, varying 500 to 12,000	Separately excited.	Synchronous or Induction.

ALTERNATING-CURRENT, SINGLE-PHASE.

Almost always constant-potential.

Circuits intended for—	Potential in Volts.		Generator should be—	Motor should be—
Incandescent lighting. Arc lighting. Sometimes constant-current. Electric power.	Primary, 1,000 or more,	Secondary, 104 or 208.	Separately excited. Also sometimes composite-wound.	Synchronous. Induction. Series. Repulsion.

Diagrams of Connections are given for each important case to show what is actually required. These merely represent the path of the currents in the simplest way, the important thing being to have these paths right, and to know which parts of wires are to be connected. The case of plants operating with only a single generator will be first considered, and then the parallel or series operation of several machines described.

Shunt Dynamo, Supplying Constant - Potential Circuit. A machine of the above type is represented in Fig. 12, with the necessary connections. The brushes are connected to the two conductors forming the main circuit; also to the field-magnet coils S*h* through a resistance-box R, to regulate the strength of current and therefore the magnetism in the field. A voltmeter is also connected to the two brushes or main conductors, to measure the voltage or electrical pressure between them. One of the main conductors is connected through an ammeter A, which measures the total current on the main circuit. The lamps L, or motors M, are connected in parallel between the main conductors or between branches from them. This represents the ordinary low-tension system for electric light and power distribution from isolated plants or central stations.

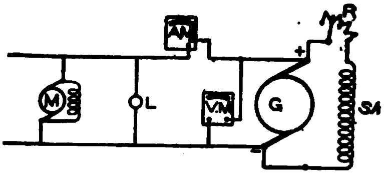


Fig. 12.

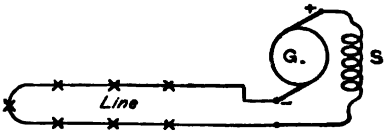


Fig. 13.

Series Dynamo Supplying Constant-Current Circuits. The connections in this case are extremely simple, the armature, field coils, ammeter, main circuit, and lamps all being connected in one series (Fig. 13), the current being kept constant. This system is used for series D. C. arc lighting.

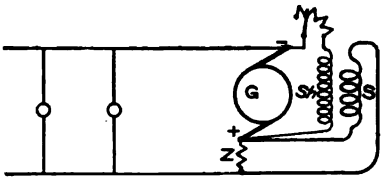


Fig. 14.

Compound Direct-Current Dynamo. This machine is a combination of the two foregoing types as regards field winding; but its load of lamps and motors are connected in parallel, as shown in Fig. 14. The resistance Z is known as the "series" shunt, and is for adjusting the percentage of compounding. The greater the resistance of Z, the greater the current passing through the series field, and the greater the compounding. This type of machine is most extensively employed in electric railway and in isolated plant work.

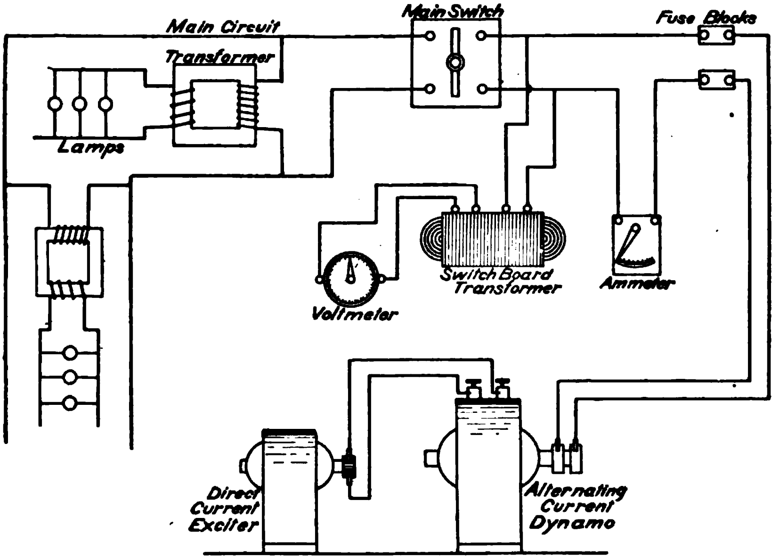


Fig. 15.

Alternating-Current Plants. The connections for a single-phase installation are shown in Fig. 15, in which the names of the different parts are given. This system is extensively used for lighting over considerable distances, and is very well adapted to street railway work. The wiring of a two-phase system is essentially double that given above, and can be treated as a system consisting of two single-phase circuits.

The wiring of a three-phase system is as shown in Figs. 16*a* and 16*b*, the former being known as the "Y" system or "Star" system, and the latter as the "Delta" (Δ) system or "Mesh" system. When the Y system is required for both lighting and power, it is arranged as shown in Fig. 16*c*.

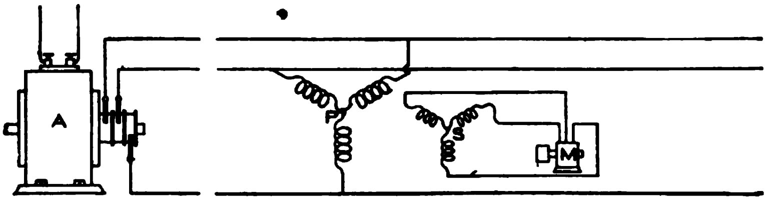


Fig. 16*a*.

The **Direction of Rotation** of the various machines is sometimes a matter of doubt or trouble. Almost any generator or motor is intended to be run in a certain direction; that is, it is called "right-handed" or "left-handed" according to whether the armature does or does not revolve like the hands of a clock, when looked at from the pulley end. Generators and motors are usually designed to be right-handed, but the manufacturer will make them left handed if specially ordered. This may be required because the other pulley to which the machine is to be connected happens to revolve left-handed; or it may be necessary in order to bring the loose side of the belt on top, or to permit the machine to occupy a certain position where space is limited.

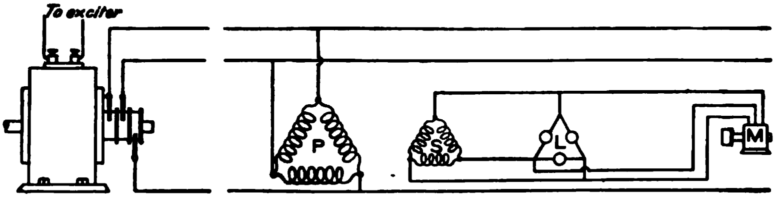


Fig. 16*b*.

To reverse the direction of rotation of an ordinary shunt (or series) direct-current bipolar motor, the brushes may simply be reversed as indicated in Fig. 17, without changing any connection. This changes the point of contact of each brush tip 180°.

If the machine is multipolar, a similar change must be made, amounting to 90° in a four-pole, 45° in an eight-pole machine, etc.

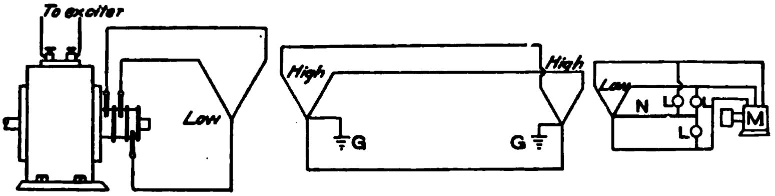


Fig. 16c

The direction of the current and the polarity of the field magnets remain the same as before; all that is changed is the direction of rotation and the position of the brushes. This applies to any machine (either motor or generator) except arc dynamos and one or two other peculiar machines, which require to be run in a certain direction to suit the regulating apparatus.

A separately excited alternating-current generator can be reversed in direction of rotation without changing any connection. A self-exciting or compound-wound alternator requires the brushes that supply the direct current to the field to be reversed upon the commutator, and their tips moved through an angle as above stated, if the rotation is to be reversed.

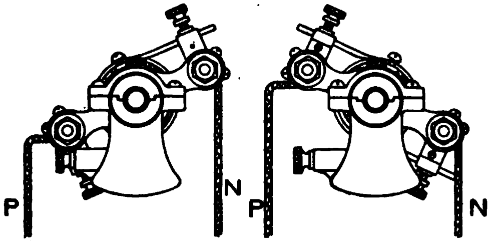


Fig. 17.

In any case, copper brushes (unless they be gauze brushes pressing radially upon the commutator) should point in the direction of rotation; but carbon brushes, particularly if they are perpendicular to the surface of the commutator, allow the armature to be revolved in either direction.

If the direction of the current from a generator is opposite to that desired, the two wires leading from it should exchange places in the terminals. If this is not desirable, the residual magnetism may be reversed by passing through the field winding a current opposite in direction to the original current.

Changing the direction of the current by reversing the main wires or otherwise, does not reverse the direction of rotation of any motor, since it reverses *both* the armature and the field. The way to reverse the direction of rotation is to reverse *either* the armature or the field connection *alone*, leaving the other the same as before.

Examination before Starting. The machine should be cleaned throughout, especially the commutator, brushes, electrical connections, etc. Any metal dust on the commutator or near electrical connections should be removed, as it is very likely to cause short circuits or grounds. Examine the machine carefully, and make sure that there are no screws or other parts that are loose or out of place. See that the oil-cups have a sufficient supply of oil, that the passages for the oil are clean, and that the feed is at the proper rate. In the case of self-oiling bearings, the rings or other means for carrying oil should work freely. See that the belt, if used, is in place, and that it has the proper tension. If the machine is being started for the first time, it should be turned a few times by hand, or run very slowly, in order to determine whether the shaft revolves easily and the belt runs on centers of pulleys.

The brushes should be carefully examined, and adjusted to make good contact with the commutator at the proper point, the switches connecting the machine to the circuit being left open. The machine should then be started with care, and brought up to full speed gradually, if possible. The person who starts either a dynamo or a motor should closely watch the machine and everything connected with it, and should be ready to throw it out of circuit and stop it instantly if the least thing seems to be wrong. He should then be sure to find out and correct the trouble before starting again.

Starting a Generator. A generator is usually brought up to speed either by starting its engine or other prime mover, or by connecting it to a source of power already in motion, The former should be attempted only by a person competent to manage steam engines or the prime mover in question. The mere mechanical connecting of a generator to a source of power is usually not difficult; but it should be done carefully and intelligently, even if it only requires throwing in a friction-clutch or shifting a belt from an idle pulley. To put a belt on a pulley in motion is difficult and dangerous, particularly if the belt is large or the speed is high; and should not be tried except by one who knows just how to do it. Even if a stick is used for this purpose, it is apt to be caught and thrown around by the machinery unless used in exactly the right way.

In many cases generators are brought to full speed before the brushes are put in contact with the commutator; but this is not necessary. If the brushes are in contact before starting, they can be more easily and perfectly adjusted, and the E. M. F. will come up slowly, so that any fault or difficulty will develop gradually and can be corrected, or the machine stopped, before any injury is done. In fact, if the machine is working alone on a system, and is absolutely free from any danger of short-circuiting any other machine or storage battery on the same circuit, it may be started while connected to the circuit, but not otherwise (see next article). With a large number of lamps connected to the circuit, the field magnetism and voltage might not be able to "build up" until the line is disconnected.

If one generator is to be connected to another or to a circuit having other generators or a storage battery working upon it, the greatest care should be taken. This coupling together of generators can be done perfectly, however, if the correct method is followed, but is likely to cause serious trouble if any mistake is made.

Two or more machines are often connected to a common circuit. This is especially the case in central stations where the load varies so much that, while one generator may be sufficient for certain hours, two, three, or more machines may be required at other times. The various ways in which this is done depend upon the character of the machines and of the circuit.

Generators may be connected together either in parallel or in series.

Generators in Parallel. In this case the + (positive or plus) terminals are connected together or to the same line, and the – (negative or minus) terminals are connected together or to the other line. The currents (*i. e.*, amperes) of the machines are thereby added, but the E. M. F. (volts) is not increased. The chief condition for the running of generators in parallel is that their voltages shall be equal, but their current capacities may be different.

For example: A generator producing 10 amperes may be connected to another generating 100 amperes, provided the voltages agree. Parallel working is therefore suited to constant-potential circuits. A generator to be connected in parallel with others or with a storage battery, must first be brought up to its proper speed, E. M F., and other working conditions; otherwise it will short-circuit the system, and might burn out its armature. Hence it should not be connected to a circuit in parallel with others until its voltage has been tested and found to be equal to, or slightly (not over 1 or 2 per cent) greater than, that of the circuit. If the voltage of the dynamo is less than that of the circuit, the current will flow back through it and cause it to run as a motor. The direction of rotation is the same, however, if it is shunt-wound; and no great harm results from a slight difference of potential; but compound-wound machines require more careful handling.

Direct-Current Dynamos in Parallel are always Shunt-Wound (or Compound-Wound). The test for equal voltages may be made by first measuring the E. M. F. of the circuit and then of the machine by one voltmeter; or two voltmeters, one connected to each, may be compared (Fig. 18); or a differential voltmeter may be used. Another method is to connect the dynamo to the circuit through a high resistance and a galvanometer; and when the latter indicates no current, it shows that the voltage of the dynamo is equal to that of the circuit. A rougher and simpler way to do this is to raise the voltage of the dynamo until its "pilot-lamp," or other lamp fed by it, is fully as bright as the lamps on the circuit, and then to connect the dynamo to the circuit. Of course the lamps compared should be intended for the same voltage and in normal condition. Be sure to connect the positive terminal of the dynamo to the positive conductor, and the negative terminal to the negative conductor (Fig. 18); otherwise there will be a very bad short circuit.

When the dynamo is first connected in this way, it should supply only a small amount of current to the circuit (as indicated by its ammeter), and its voltage should then be gradually raised until it generates its proper share of the total current; otherwise it will cause a sudden jump in the brightness of the lamps on the circuit.

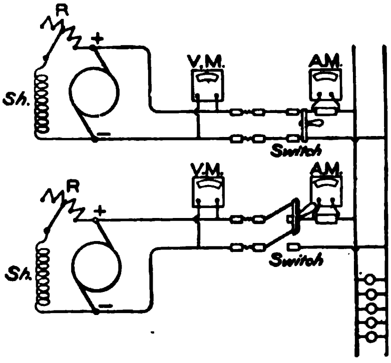


Fig. 18.

Series-Wound Dynamos in Parallel Not Used. If the machine is series-wound, the back current just described would cause a reversal of field magnetism and a very bad short circuit of double voltage. In fact, series dynamos in parallel are in unstable equilibrium, because if either tends to generate too little current, its own field, which is in series, is weakened, and thus still further reduces its current and probably will reverse the machine. This arrangement is therefore not used. One way in which this difficulty might be overcome is by causing each to excite the other's field magnet, so that if one generates too much current, it strengthens the field of the other and thus counteracts its own excess of power.

Another plan is to excite both fields by one machine, or, better, by both machines jointly, which is accomplished by connecting together the two + brushes and the two – brushes respectively, by the line and by what is called an **equalizer** (Fig. 19). In this way the electrical pressure at the terminals of the two armatures is made the same, and the currents in the two fields are also made equal. Series machines are not often run in parallel, but the principles just explained help the understanding of the next case, which is very important.

Compound Dynamos in Parallel. Since the field magnets of these machines are wound with series coils as well as with shunt coils, the coupling of them is a combination of the shunt and series cases just described.

The manner of connecting two or more compound dynamos to operate in parallel, is represented in Fig. 20, A being the armature, B the series, and C the shunt-field coils. R is the shunt-field rheostat; D and F are switches connecting the main terminals of the machine with the bus bars G and I, respectively; and E is a switch to connect the equalizer H with the brush end of the series coil B.

Assume that machine No. 1 is already in operation with its switches D, F, and E closed, and that it is desired to have machine No. 2 thrown in circuit. The procedure is as follows:

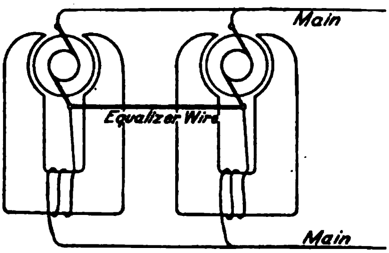


Fig. 19.

Bring machine No. 2 up to its rated speed, and adjust its pressure by means of the shunt-field rheostat until it is a little greater (about 1 per cent) than the difference of potential between the bars G and I. This fact may be ascertained by comparing two voltmeters connected to the dynamo and to the bus bars respectively; or by means of a single voltmeter connected through a double-throw switch, first to one and then to the other, which avoids the error due to a difference between two instruments. Another plan is to employ a differential voltmeter, that is, one having two windings on the movable coil, so that it indicates directly the difference in voltage between the two parts of the system.

After the pressure of the *incoming* dynamo has been properly regulated, the three switches E, F, and D are closed in the order named. If these points should be closed simultaneously by means of a triple-pole switch, a considerable current might flow through the series field winding, tending to increase still further the voltage of this dynamo, at the same time taking current away from the series coils of the other machines, and thereby reducing their potential. The shifting of the load thus produced might be so sudden and so great as to be objectionable. This action, however, is not of sufficient importance to overbalance the many advantages afforded by the use of a switch in which the three are combined as a triple-pole switch, thus guarding against the possibility of any accident due to closing the wrong circuit first.

After the machines have been thrown in parallel, their voltages should be adjusted by the shunt-field rheostats so that the load is properly divided between them.

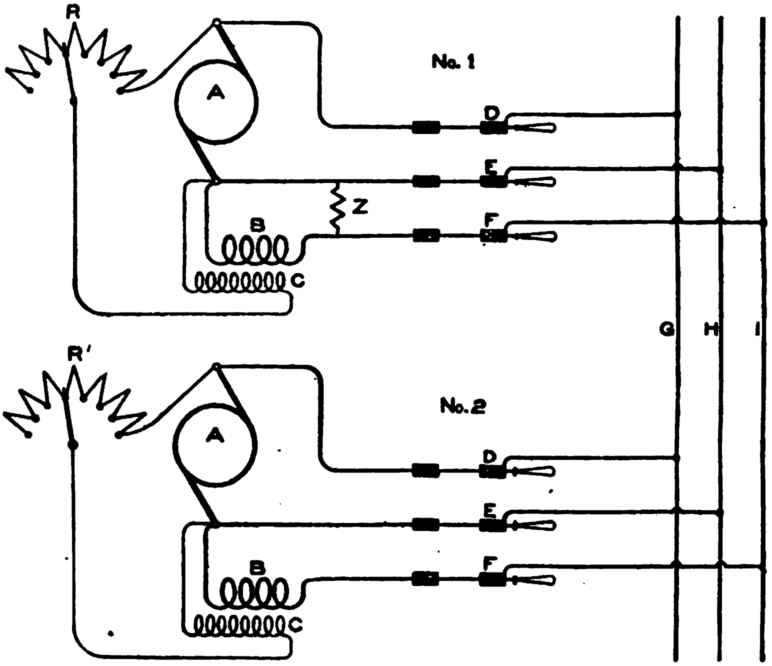


Fig. 20.

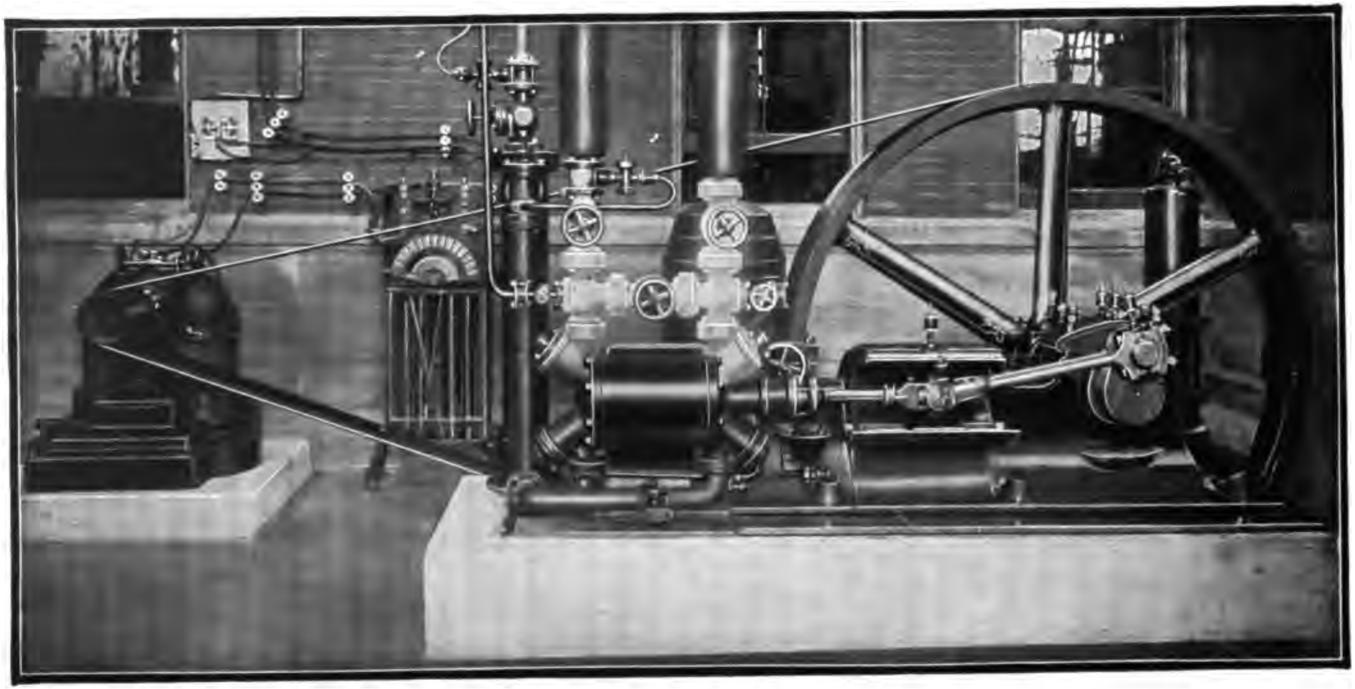
Compound dynamos of different size or current capacity may also be coupled as described, provided, of course, their voltages are equal; and provided also that the resistances of the series field coils, together with their leads to the bus bar, are inversely proportional to the current capacities of the several machines; that is, if a dynamo produces twice as much current, its series coil and lead should have half the resistance. It is further necessary that the two machines should agree in their action, so that a given increase in load will produce the same effect upon their voltages.

If they are not in agreement, they may be adjusted by slightly increasing the resistance of the series coil of that machine which tends to take too large a share of the load. This may be done by simply interposing a few extra feet of conductor of the same current capacity as the series coil, between the latter and the main conductor or bus bar. The shunts which are almost always used to adjust the effect of the series coils in compound dynamos (shown at Z in machine No. 1, Fig. 20), operate properly in the case of machines working *singly*, but are worthless for machines in parallel. The *resistances of the series coils themselves* must be adjusted as explained above, when two or more compound machines are run in parallel. The use of iron for this shunt makes the compounding effect in the dynamo more uniform, because its resistance, rising as the current through it increases, throws a greater fraction of the current through the series coils at full load, and compensates for the fact that the field magnetism, and consequently the voltage, does not increase proportionately with the increasing load current.

Shunt-wound dynamos run in parallel tend to steady each other, for, if one happens to run too fast, it has to do more work, which opposes the increase of speed; and it also takes part of the load off the other machines, which makes them run faster, thus producing equality. This mutual regulation will take care of any slight difference between machines, such as that caused by the slip of the belt, or even small differences in the governing action of the different engines that may be driving them. Compound-wound dynamos have very much less mutual regulation, owing to the effect of the series coil; and it is necessary that their speeds, voltages, etc., should regulate much more exactly than with simple shunt machines. They often work badly together owing to carelessness or to imperfect agreement between them, but with proper care and good apparatus they run well in parallel.

If generators are located at considerable distances from the switchboard, the equalizing connection may be run directly from one machine to the other with the equalizing switch (E, Fig. 20) on the frame of each, instead of running to the switchboard. This saves copper, especially in the case of large generators.

Alternators in Parallel. To run two alternators in parallel,



12-TON LINDE REFRIGERATING MACHINE.

Operated by an Electric Motor.

Fred W. Wolf Company.

several conditions have to be fulfilled: The incoming machine—as in the case of direct-current machines—must be brought up to nearly the same voltage as the first one; it must operate at exactly the same frequency; and, at the moment of switching in parallel, it must be in phase with the first machine. This correspondence of frequency and phase is called **synchronism.**

It is impossible with mechanical speed-measuring instruments to determine the speed as accurately as is necessary for this purpose. There is, however, a very simple method of electrically determining small differences in speed or frequency. In Fig. 21, let M and N represent two single-phase alternators, which can be connected by means of the single-pole switch AB Across the terminals of the switch is connected an incandescent lamp L, capable of standing twice the voltage of either machine. When AB is open, the circuit between the machines is completed through L. The two machines may be connected in parallel as follows: Assuming machine M already in operation, bring up machine N to approximately the proper speed, and voltage; then watch lamp L. If machine N is running a very little slower or faster than machine M, the lamp L will glow for one moment and be dark the next. At the instant when the voltages are equal in pressure and phase, L will remain dark; but when the phases are displaced by half a period, the lamp will glow at its maximum brilliancy. Since the flickering of the lamp is dependent upon the difference in frequency, the machines should not be thrown in parallel while this flickering exists. The prime mover of the incoming machine must be brought to the proper speed; and the nearer machine N approaches snychronism, the slower the flickering. When it is very slow, we can use the moment the lamp is dark to throw the machines in parallel by closing the switch across AB. The machines are then in phase, and tend to remain so, since if one slows down the other will drive it as a motor. It is better to close the switch when the machines are approaching synchronism than when they are receding from it, that is, at the instant the lamp becomes dark.

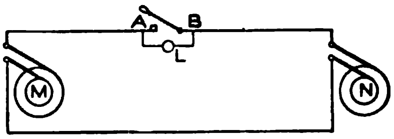


Fig. 21

This method of synchronizing is open to the following objections:

(*a*) The lamps may be dark with considerable difference in voltage. For instance, a 110-volt lamp is dark with a pressure of 20 to 25 volts.

(*b*) The lamp may be dark owing to a broken filament.

It may thus happen, with this arrangement, that the machines are placed in parallel while there is a considerable difference of voltage or phase existing, and an excessive rush of current will result.

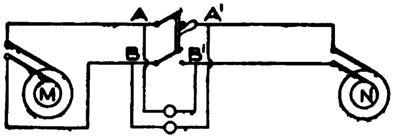


Fig. 22

A method not open to the above objections is shown in Fig. 22. The machines to be switched in parallel are each connected to the bus bars by means of double-pole switches. Two incandescent lamps, of the machine voltage, are cross-connected as shown. If the machines are in phase and the voltages generated are equal in value, the difference of potential between A and a given point is the same as that between A′ and the same point; likewise B and B′ have the same relative potential values. Hence a lamp connected between A and B′ would burn with the same brilliancy as if it were connected directly across AB; likewise with the other lamp. If, however, the machines happen to be directly opposite in phase but to be generating voltage of the same value, A and B′ are of the same relative potential value, and B and A′ are likewise of the same value; hence lamps cross-connected as in Fig. 22 would be dark. At any other phase difference the lamps will glow, but not so brightly as when in phase. Hence, with this arrangement, the machines should be thrown in parallel when the lamps are on the verge of maximum brightness, a condition readily determined, but not possible with the first method.

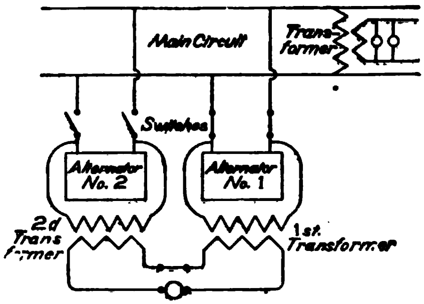


Fig. 23.

The connections as shown in Figs. 21 and 22 are not directly applicable to high-tension working, but require the introduction of transformers as shown in Fig. 23, which is a modification of Fig. 22. The secondaries (of, say, 50 volts each) should be connected in series with each other and to one 100-volt lamp. When the two machines are opposed in phase, the lamp is dim. If the lamp flickers badly, the phase is not right; but if the lamp is steady at full brightness, the machines are in phase, and they may be connected without disturbing the circuit, by closing the main switch.

If alternators are rigidly connected to each other or to the engine, so that they necessarily run exactly together, there is no need of bringing them into step each time, but they should be adjusted to the same phase in the first place.

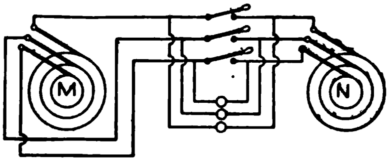


Fig. 24.

The connections of the synchronizing lamps of a three-phase system are similar to those for a single-phase system. For instance, the method employed in Fig. 21 may be extended, and lamps connected as in Fig. 24. If the three lamps simultaneously become dark or bright, the connections are correct, and the three switches may be closed at an instant of darkness. It may happen, however, that the lamps do not become bright or dark simultaneously but successively This indicates that the order of connection of the leads of one machine does not correspond with that of the other. In this case, transpose the leads of one machine until the proper or simultaneous action of the lamps is obtained. After the machines have been properly connected, it is sufficient to synchronize with one of the lamps. Similarly, with high-tension systems, only a single-phase transformer is required, connected as shown in Fig. 25.

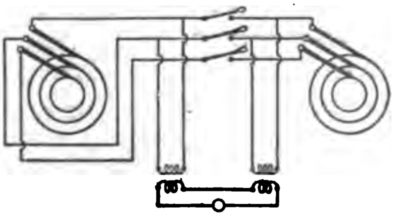


Fig. 25.

Generators in Series. This arrangement is less common than parallel working, and does not usually operate so well, except with series-wound machines on arc circuits, which is very successful. The conditions are exactly opposite to those in the preceding group—generators in parallel.

To connect machines in series, the positive terminal of one must of course be connected to the negative terminal of the next, and so on. Each must have a current capacity equal to the maximum current on the circuit, but they may differ to any extent in E. M. F. The voltages of machines in series are added together; and therefore danger to persons, insulation, etc., is increased in proportion.

Series-Wound Direct-Current Dynamos in Series are connected in the simple way represented in Fig. 26; but, usually machines connected in series are for arc lighting—for example, when two dynamos, each of 40 lights capacity, are run on one circuit of 80 lamps, in which case the dynamos usually have some form of regulator. These regulators do not usually work well together, because they are apt to "seesaw" with each other. This difficulty may be overcome either by connecting the regulators so that they work together, or by setting one regulator to give full E. M. F. and letting the other alone control the current. This latter plan can be followed only when the variation in load does not exceed the power of one machine. Constant-current dynamos having regulators with little inertia in the moving parts, and thus little tendency to "overshoot," such as the Brush machine, can be run in series without much trouble.

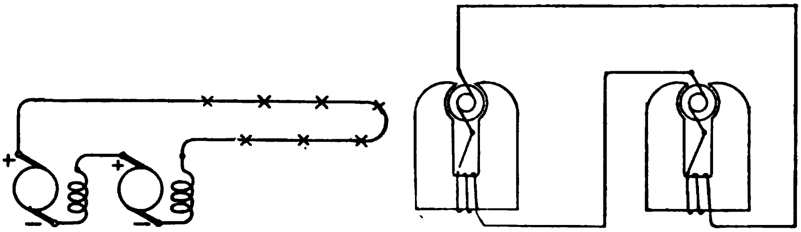


Fig. 26.

Shunt or Compound Dynamos in Series run well, provided the shunt-field coils are connected together to form one shunt across both machines. If the machines are compound, all of the series coils must be connected in series with the main circuit. Another plan is to connect each shunt field so that it is fed only by the armature of the other machine ; or both the shunt coils may be connected so as to be fed by one armature, the series coils being in the main circuit as before.

Alternators in Series. The synchronizing tendency which makes it possible to run alternators in parallel, causes them to get out of step and become opposed to each other when it is attempted to run them in series. It is therefore impracticable to run them in series unless their shafts are rigidly connected so that they must run exactly in phase and thus add their waves of current instead of counteracting each other. This case rarely occurs.

Dynamos on the Three-Wire System (Direct-Current). In the ordinary three-wire system for incandescent lighting and power service, no particular precautions are required in starting or connecting the machines; and either of the two arrangements shown in Figs. 27*a* and 27*b* may be adopted. The two sides of the system are almost independent of each other, and form practically separate circuits, for which the middle or neutral wire acts as a common conductor. There is, however, a tendency for the dynamos (Fig. 27*a*) to be reversed in starting up, in shutting down, or in the case of a severe short circuit. This can be avoided by exciting the field coils of all the dynamos from one side of the system, or from a separate source. To obtain good regulation, it is necessary to balance the load equally on both sides of the system. It is advisable to employ 220-volt motors on 110-volt 3-wire systems, and to connect them across the outside conductors so that the motor load shall not unbalance the system.

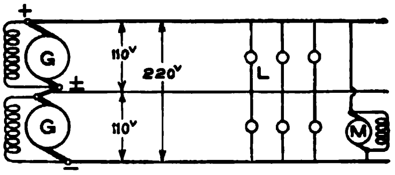


Fig. 27*a*.

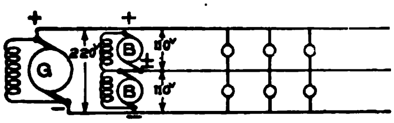


Fig. 27*b*.

KINDS OF MOTORS, CONNECTIONS, AND STARTING.

The general instructions relating to the adjustment of brushes, screws, belt, oil-cups, etc., given in relation to the generator, should be carefully followed preparatory to starting a motor. The actual starting of a motor is usually a simple matter, since it consists merely in operating a switch; but in each case there are one or more important points to be considered

CONSTANT-POTENTIAL D. C. CIRCUITS.

Shunt-Wound Motor. A motor to operate at nearly constant speed, with varying loads, on a D. C. constant-potential system (110- or 220-volt lighting circuits) is usually plain shunt-wound. This is the commonest form of stationary motor. The field coils are wound with wire of such a size as to have the proper resistance and resulting magnetizing current; and since the potential applied is practically constant, the field strength is constant.

In starting shunt motors, no trouble is likely to occur in connecting the field to the circuit. The difficulty is with the armature current, because the resistance of the armature is very low in order to get higher efficiency and constancy of speed, and the rush of current through it in starting might be twenty or more times the normal number of amperes. To avoid this excessive current, motors are started on constant-potential circuits through a rheostat or "starting-box" containing resistance coils.

The main wires are connected through a branch cut-out (with safety fuses), and preferably also a double-pole knife switch Q, to the motor and box, as indicated in Fig. 28. When the switch Q is closed, the arm S being in its left-hand position, the field circuit is closed through the contact stud *f*, and the armature circuit is closed through the resistance coils *a*, *a*, *a*, which prevent the rush of current referred to. The motor then starts, and as the speed rises it generates a counter E. M. F., so that the arm S can be turned as shown until all the resistance-coils *a*, *a*, *a*, are cut out, and the motor is directly connected to the circuit and running at full speed. The arm S should be turned slowly enough to allow the speed and counter E. M. F. to come up as the resistances *a*, *a*, *a* are cut out. The arm S should positively close the field circuit first, so that the magnetism reaches its full strength (which may take several seconds) before the armature is connected.

In the arrangement shown in Fig. 28 the release magnet has its coils in series with the field. As long as the motor is in operation, the core is energized and the arm S is held in the position shown. If, however, the current supplied to the motor is cut off and the motor comes to rest, the core of the magnet loses its attractive force, and the arm S is released, being automatically moved back to the starting position by a spring.

The coils *a*, *a*, *a* are made of comparatively fine wire, which can carry the current only for a few seconds in a "starting-box;" but if the wire is large enough to carry the full current continuously, it is called a "regulator," because the arm S may be left so that some of the resistances *a*, *a*, *a* remain in circuit, and they will have the effect of reducing the speed of the motor, which is often very desirable.

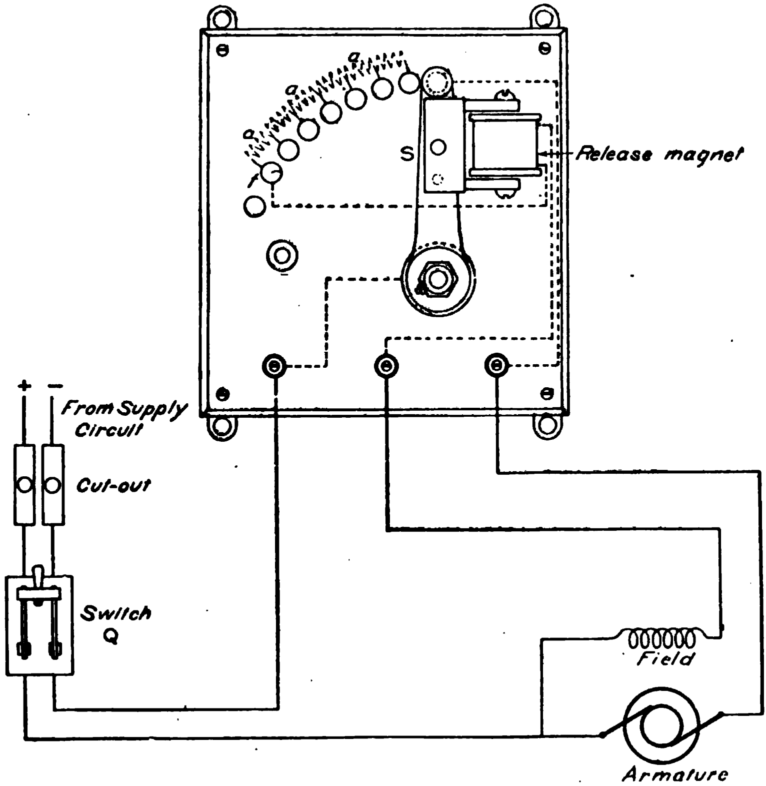


Fig. 28.

In some cases where a circuit is used exclusively for a single motor, the speed is regulated without heavy resistances by varying the E. M. F. of the dynamo which supplies the circuit. The dynamo regulator is then placed near the motor. The advantage is that the regulator is not compelled to control a heavy current, but a special circuit of unvaried pressure must be provided to keep the field of the motor constant.

The speed control of a shunt motor may be simply obtained as follows:

a. For lower speeds, insert resistance in series with the armature circuit. The resulting I. R. drop reduces the value of the voltage applied to the armature terminals, and thus reduces the speed.

b. For higher speeds, insert resistance in the shunt-field circuit. This reduces the magnetic flux, and to generate the same C. E. M. F. the motor must speed up.

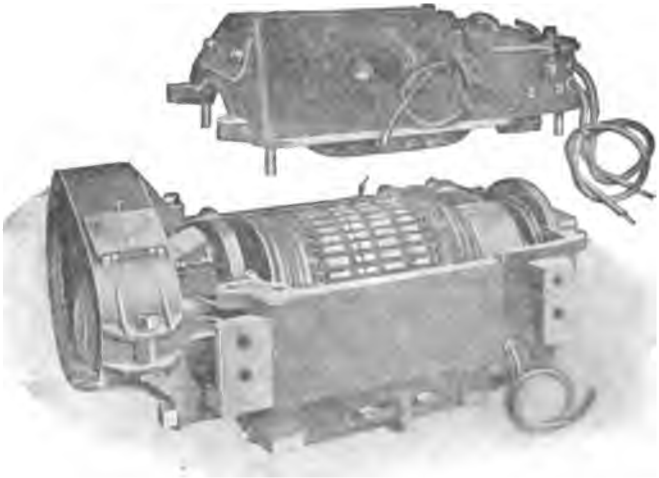


Fig. 29.

The field circuit of a shunt motor should never be opened while pressure is still applied to the armature terminals, as under these conditions the armature current becomes very excessive and the armature is likely to race and probably be damaged. A moderate decrease in field strength only is allowable ; otherwise sparking becomes excessive.

Series-Wound Motor. The ordinary electric railway motor on the 550-volt trolley system is the chief example of the class (Fig. 29.) Motors for fans, pumps, or electric elevators and hoists are either of this kind or of the compound type. A rush of current tends to occur when the series type of motor is started, similar to that in the case just described ; but it is less, because the field-coils are in series, so that their resistance and self induction reduce the excess. Furthermore, the counter E. M. F. is greater even at low speed because the heavy current produces a strong field.

The connections as indicated in Fig. 30 are very simple, the armature, field-coils, and rheostat all being in series and carrying the same current.

The series-wound motor on a constant-potential circuit does not have a constant field strength, and does not tend to run at constant speed, like a shunt motor. In fact it may "race" and tear itself apart if the load is taken off entirely; it is therefore suited only to railway, pump, fan, or other work where variable speed is desired, or where there is no danger of the load being removed or a belt slipping off. It is also used where the potential is subject to sudden and large drops, as on the ends of long trolley circuits, because in such a case a shunt motor becomes momentarily a generator and sparks very badly. The fields of series motors are sometimes "overwound," that is, so wound that they will have their full strength with even one-half or one-third of the normal current. The objects are to secure a nearly constant speed with varying loads, to enable the motor to run at high efficiency when drawing small currents, and to prevent sparking at heavy loads.

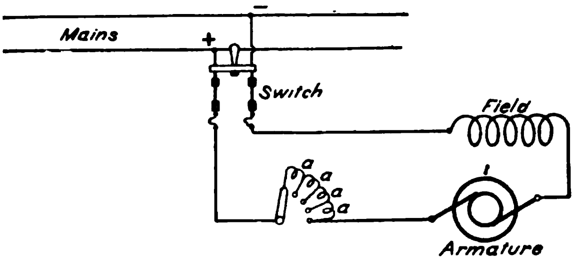
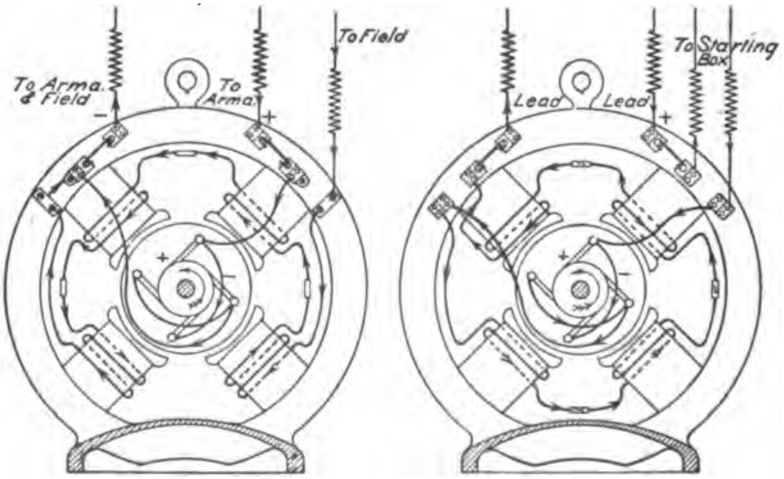


Fig. 30.

In multipolar motors having more than two field-coils, the coils are all connected together, and are equivalent to the single pairs of coils shown in the several diagrams. Being separated, however, it is sometimes necessary to trace out the connections. Fig. 31 represents the necessary connections for a four-pole motor, shunt-wound and series-wound.

Differentially-Wound Motor. This is a shunt-wound motor with the addition of a coil of large wire, on the field, connected in series with the armature in such a way as to oppose the magnetizing effect of the shunt winding and weaken the field, thus causing the motor to speed up when the load is increased, as an offset to the slowing-down effect of load.

It was formerly used, for obtaining very constant speed, but it has been found that a plain shunt motor is sufficiently constant for almost all cases. The differential motor, if overloaded, has the great disadvantage that the current in the opposing (series) field-coil becomes so great as to kill the field magnetism; and instead of increasing or keeping up its speed, the armature slows down or stops, and is likely to burn out; whereas a plain shunt motor can increase its power greatly for a minute or so when overloaded, and will probably throw off the belt or carry the load until the latter decreases to the normal amount.



Shunt-wound Motor. **Series-wound Motor.**

Fig. 31.

Compound-Wound Motor. This type of motor is also provided with a shunt and a series-field winding, Fig. 32, but in this instance they magnetize the field in the same direction, or, in other

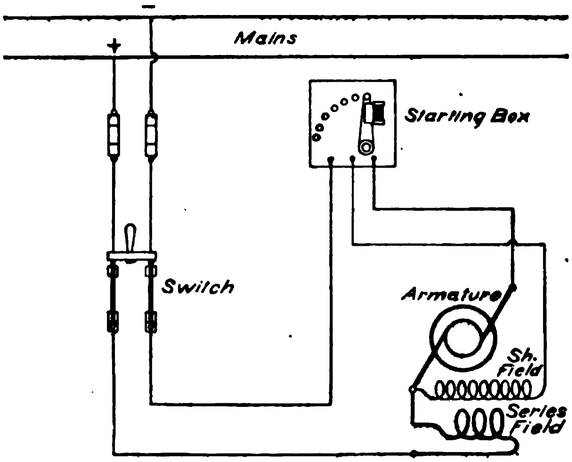


Fig. 32.

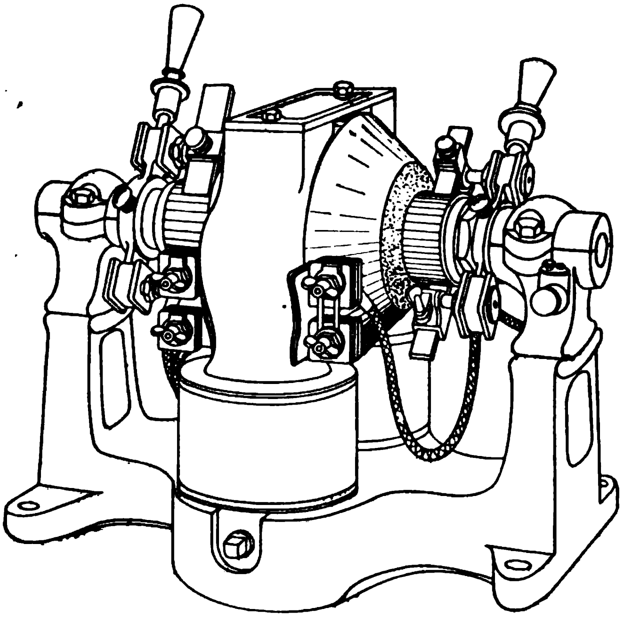


Fig. 33.

words, their effect is cumulative. This type of motor possesses the powerful starting torque feature of the series motor, but a less variable speed with varying loads. It is employed where a great starting torque and a fairly uniform running speed are required, as, for example, with electric hoists or elevators.

Dynamotors, Fig. 33, and also motor-generator sets, are started in the same way as motors; that is, the motor portion of the machine is connected to the circuit and operated precisely like the corresponding kind of motor. Usually the motor part is plain shunt-wound, and is supplied with current from a constant-potential circuit. It is therefore connected and started in the manner shown and described on page 40.

The current generated by the dynamo portion of the dynamotor may be taken from the terminals, and used for any purpose to which it is suited. The E. M. F. or current produced may be regulated by varying the resistance in the armature circuit of either the motor or dynamo. In case the dynamo armature has a separate field magnet, the E. M. F. and current may be controlled by regulating the magnetic strength of this field, or the machine may be compounded or even "over-compounded." But if the armatures of both motor and dynamo are acted upon by the same field, the E. M. F. of the dynamo cannot be varied except by inserting resistances in the circuit of either armature or by shifting the brushes. But the latter method will be likely to cause sparking.

ALTERNATING-CURRENT MOTORS.

Alternating-current motors operate on constant-potential circuits, since almost all A. C. systems are of this kind. There are several types of these motors, the simplest of which is the *series machine* for single-phase current. This is similar to the corresponding D. C. motor, except that its field must be laminated.

It possesses the characteristic of large starting torque and lends itself to variable speed control like its direct current counterpart and is coming into use very rapidly for electric railway work. Both the General Electric and the Westinghouse Electric and Manufacturing Companies have placed such machines upon the market and they are already in operation on a number of electric roads where they are giving satisfaction.

This type of motor while retaining practically all the advantages of the direct-current series motor for electric railway work permits the use of alternating current on the trolley with all its attendant advantages. A frequency of 25 seems likely to become the standard for such work. The cars can be operated on existing direct-current lines and the multiple unit control system can be applied to cars equipped with single-phase motors.

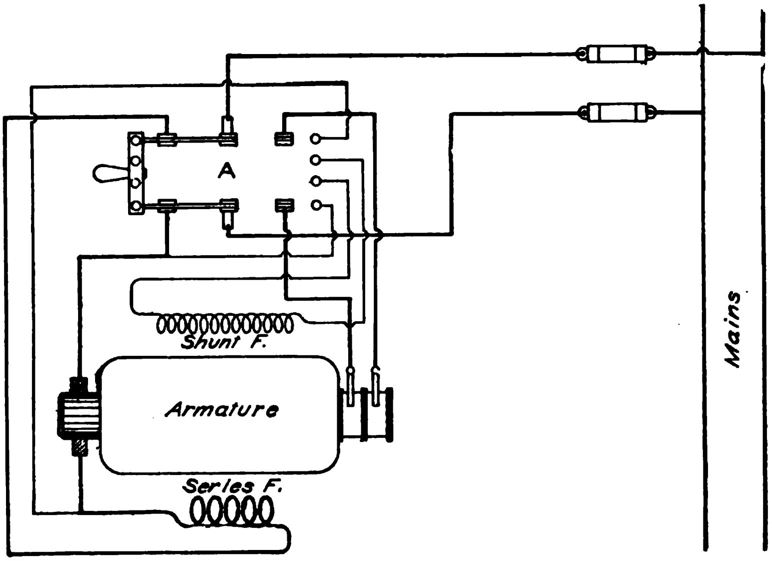


Fig. 34.

An ordinary single-phase alternator can be used as a motor; but it must first be brought up to synchronism with the supply generator by means of some auxiliary starting device (steam engine, polyphase induction motor, etc.) before the load can be applied. In this form the machine is known as the *single-phase synchronous motor.* The condition of synchronism is determined by one of the methods described in the paragraph on "Alternators in Parallel." After the motor is in synchronism it may be connected to the circuit by closing its supply switch; and it will then continue to run at an absolutely constant speed, unless heavily overloaded, when it falls out of step and stops.

On account of these features, the synchronous motor is not to be recommended for general application. Various manufacturers, notably the Wagner Electric Company, and the Fort Wayne Electric Company, manufacture self-starting, single-phase synchronous motors, usually limited, however, to the smaller sizes. The construction and action of the Fort Wayne motor (Fig. 34), which is a combination of the two preceding types, are as follows: The armature core is provided with a double winding, one equipped with collecting rings, and the other with an ordinary commutator. The field magnet, which is laminated, is wound with two separate circuits, one being of low resistance and a small number of turns, the other of high resistance and many turns, like an ordinary shunt-field winding. In starting, the motor runs as a series machine, the low-resistance field being in series with the commutated armature winding and the line. When it has reached synchronism, the switch A, on the top, is thrown over to the right, and the supply line connected with the collector rings and the corresponding armature winding; while the commutated end is connected to the other field winding, and thus provides the direct current necessary for field excitation.

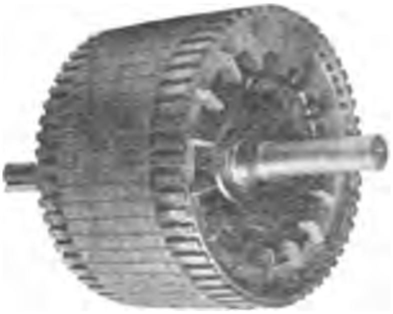


Fig. 35.

In addition to the single-phase there is also the *polyphase synchronous motor*. This latter form, however, is self-starting without field current, but will not carry a load until it is running in synchronism. When this condition is reached, the field circuit should be closed before applying the load.

A great advantage of the synchronous motor is that when its field is over-excited, it draws a leading current from the line, thus acting like a condenser and tending to neutralize the inductive effect of other machinery, so that the power factor of the whole system is raised. The most extensive use of the synchronous motor is as a part of the rotary converter, which is employed to convert alternating into direct currents, for traction and electro-chemical purposes.

The satisfactory use of alternating currents for power purposes depends mainly on the *polyphase induction motor*, as in this form the A. C. motor is self-starting with considerable torque and operates at a practically constant speed from no load to a heavy overload. Induction motors are designed for the standard voltages and frequencies.

In most induction motors now built, the primary, or part into which the currents from the line are led, is the stationary member, or *stator*. The secondary, in which the induced currents are set up, is the rotating member, or *rotor*. There are two kinds of rotor windings, the simpler being that known as the "squirrel-cage." This winding is made up of a number of copper bars, equally spaced around the rotor core, and imbedded therein. The terminals of these inductors are interconnected, or short-circuited, by means of heavy copper rings placed at both ends of the core, as shown in Fig. 35.

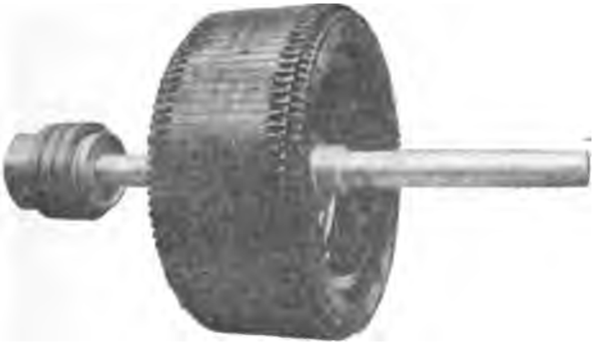


Fig. 36.

The other form of winding is of the drum species, usually three-phase, Y-connected; and the coils are located at 120° intervals (the arc between centers of adjacent poles being called 180°) with respect to each other. The free ends of the windings are respectively brought out to three slip or collecting rings; and on this account this type of rotor is frequently called the "slip-ring" rotor (Fig. 36).

Starting Induction Motors. In small sizes, up to 3 or 5 H. P., the induction motor can be started by connecting its stator terminals directly to the line. But with larger sizes the inrush of current is excessive and likely to disturb the system; accordingly some form of starting device is usually necessary.*

Starting Compensators. This inrush of current can be avoided by inserting a starting resistance, or inductance, in series with the primary winding and the line, or by using some other means of cutting down the applied E. M. F. The torque of an induction motor decreases as the square of the applied voltage, so that this method of starting results in a greatly reduced starting effort. However, in many instances, motors are not started up under full load, so that this may not be a serious objection.

While a resistance could be employed as described, it is more economical to employ an auto-transformer (that is, a transformer having but one coil, which serves as both a primary and a secondary), or *compensator*, as it is called when used for this purpose Compensator connections for a three-phase motor are represented in Fig. 37. The compensator consists of coils *a*, *b*, and *c*, wound on a laminated-iron core, each coil being provided with a number of taps, 1, 2, 3, etc. The pressure applied to the motor at starting is proportioned to the amount of each coil included in the circuit. While the compensator winding is provided with taps, only that one which is most suitable for the work is used after the equipment is permanently installed. When the switch is in the

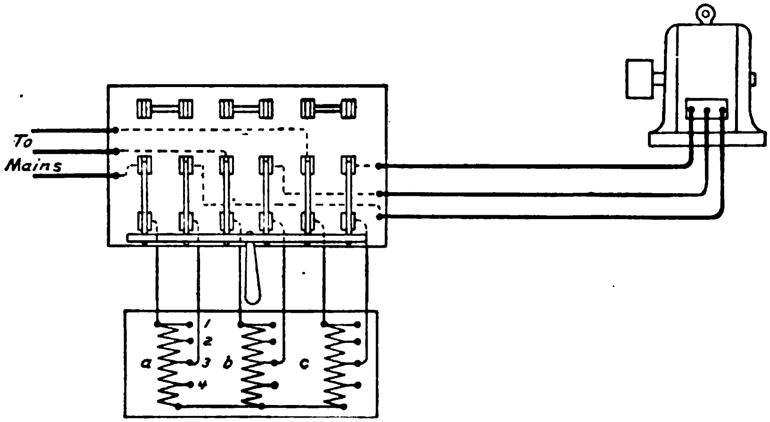


Fig. 37.

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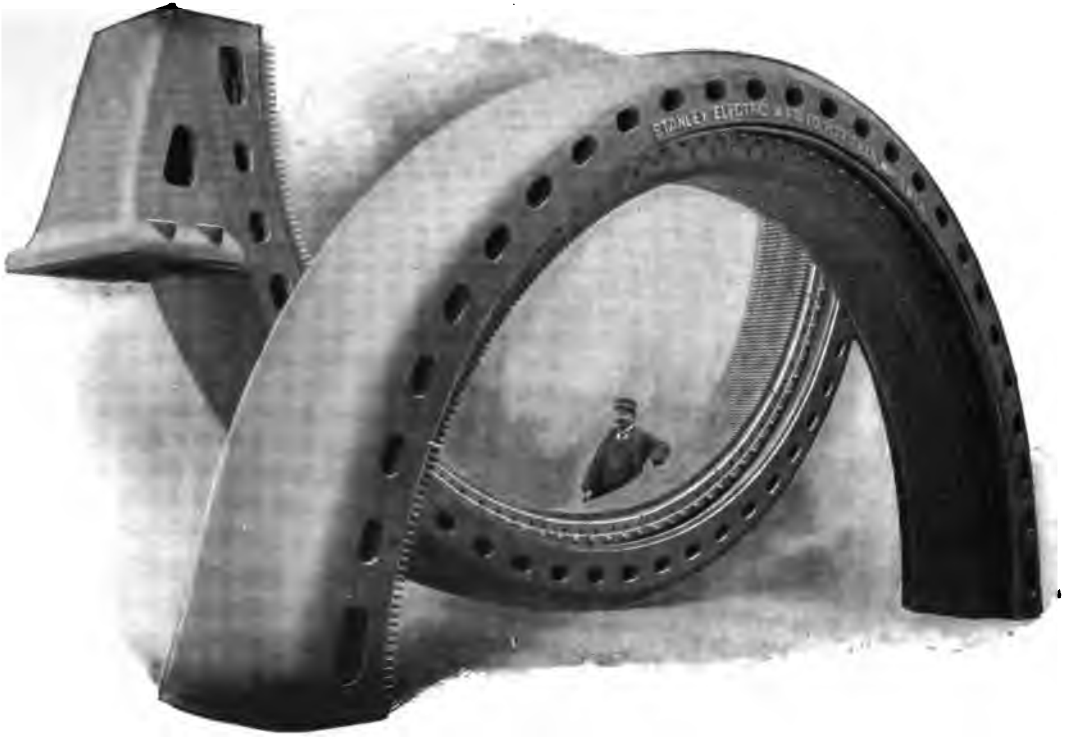
* This inrush of current is frequently three times the rated load current.



ARMATURE HALVES OF S.K.C. GENERATOR.

lower position as indicated, a part of each coil is in series with each leg of the system leading to the motor; and the applied voltage is correspondingly cut down. After the motor reaches its rated speed, the switch is thrown to the upper or running position, and the stator or primary terminals are connected directly to the line. The compensator thus prevents an excessive inrush of current, and gives the motor a smooth start, although it decreases the starting torque, compared with that due to full line pressure.

Speed Regulation of Induction Motors. For some classes of work, it is desirable to have induction motors arranged so that their speed can be controlled, the usual methods being:

a. The insertion of a variable resistance in the rotor circuit.
b. Cutting down the voltage applied to the stator, as just described.

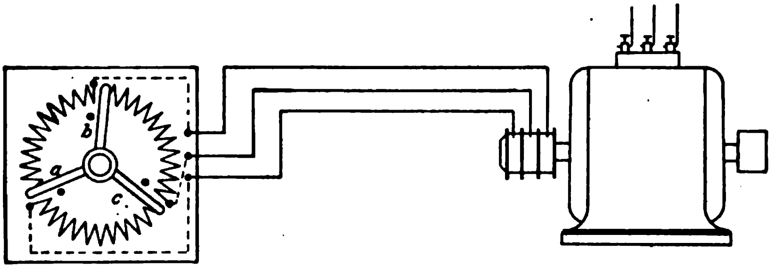


Fig. 38.

The more satisfactory method of speed control, is that with variable resistance inserted in the rotor circuit, the power-factor and hence the efficiency of the system being greater at reduced speeds than with the compensator or equivalent device. It requires, however, the use of collector rings, connecting brushes, and leads, since a resistance for continuous service is too bulky to be placed within the machine. Still further, the heat developed in the resistance would heat the machine too much. The controller itself looks like an ordinary trolley car controller, but for simplicity it is represented as a three-armed controller (Fig. 38) in which the arms *a*, *b*, and *c* are in electrical contact under the handle. The resistance is provided in three sets, one for each free end of the rotor winding; and each set is subdivided so that it can be gradually cut out of circuit as the motor speed increases. Frequently the controller is so arranged that the first motion of the handle closes the supply lines, and subsequent motions vary the resistances in the rotor circuit, thus performing the function of a supply switch and speed controller.

Another method of speed control, is to have the winding on the stator arranged so that by means of a suitable controlling switch, the number of poles can be changed. This is a very economical method from the electrical standpoint, and gives a very wide range of control, but, on account of its complexity and cost, is used only to a limited extent.

In general, the induction motor does not allow of the same range of speed control as does the direct-current motor, and the methods employed for this purpose are not efficient.

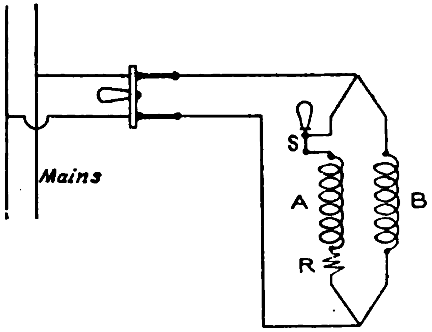


Fig. 39.

Single-Phase Induction Motor. A two or three-phase induction motor will operate fairly well, if, after reaching full speed, all but one of the phases be cut out. It will not however start from rest under the influence of single-phase excitation. Hence, to start an induction motor from the lines of a single-phase system, currents differing in phase must be obtained. This is accomplished by connecting the two primary windings A and B (in the case of a two-phase motor) in parallel to the single-phase mains, at the same time connecting in series with one winding a resistance R (Fig. 39). The currents flowing through these two windings will then differ in phase, one leading the other on account of a difference in their constants, and will thus produce a rotating field, and the motor will then start up.* When the motor has reached full speed, one phase may be cut out by opening the switch at S, and the machine will carry its load. The resistance R may be replaced to advantage by a condenser, especially on small machines. Such a machine is commonly called a "split-phase" motor.

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* This field is not a rotary field in the full sense, being elliptical in character.

DIRECTIONS FOR RUNNING GENERATORS AND MOTORS.

After any one of these machines has been properly started, it usually requires little attention while running; in fact, generators or motors frequently operate all day without any care whatever.

In the case of a machine that has not been run before or has been changed in any way, it is wise to watch it closely at first. It is also well to give the bearings of a new machine plenty of oil at first, but not enough to run on the armature, commutator, or any part that would be injured by it; and to run the belt (if used) rather slack until the bearings and belt are in easy working condition.

If possible, a new machine should be run without load or with a light one for an hour or two, or for several hours in case of a large machine; and it is bad practice to start a new machine with its full load or even a large fraction of it. This is true even if the machine has been fully tested by its manufacturer and is in perfect condition, because there may be some fault in setting it up or some other circumstance that would cause trouble. All machinery requires some adjustment and care for a certain time to get it into smooth working order.

When this condition is reached the only attention required is to supply oil when needed, keep the machine clean, and see that it is not overloaded. A generator requires that its voltage or current should be observed and regulated if it varies. The attendant should always be ready and sure to detect the beginning of any trouble, such as sparking, heating, noise, abnormally high or low speed, etc., before any injury is caused, and to overcome it. Such directions should be pretty thoroughly committed to memory in order promptly to detect and remedy any trouble when it occurs suddenly, as is usually the case. If possible, the machine should be shut down instantly when any indication of trouble appears, in order to avoid injury and give time for examination.

Keep all tools or pieces of iron or steel away from the machine while running, as they might be drawn in by the magnetism, perhaps getting between the armature and pole pieces and ruining the machine. For this reason use a zinc, brass, or copper oil-can instead of one of iron or "tin" (tinned iron)

Particular attention and care should be given to the commutator and brushes, to see that the former keeps perfectly smooth and that the latter are in proper adjustment. (See "Sparking.")

Never lift a brush while the machine is delivering current unless there are one or more other brushes on the same side to carry the current, as the spark might make a bad burnt spot on the commutator, or might burn the hand.

Touch the bearings and field coils occasionally to see whether or not they are hot. To determine whether the armature is running hot, place the hand in the current of air thrown out from it by centrifugal force.

Special care should be observed by any one who runs a generator or motor, to *avoid overloading* it, because this is the cause of most of the troubles which occur.

Personal Safety. Never allow the body to form part of a circuit. While handling a conductor, a second contact may be made accidentally through the feet, hands, knees, or other part of the body, in some peculiar and unexpected manner. For example, men have been killed because they touched a "live" wire while standing or sitting upon a conducting body.

Rubber gloves or rubber shoes, or both, should be used in handling circuits of over 500 volts.* The safest plan is not to touch any conductor while the current is on; and it should be remembered that the current may be present when not expected, owing to an accidental contact with some other wire or to a change of connections. Tools with insulated handles, or a dry stick of wood, should be used instead of the bare hand.

The rule to use *only one hand* when handling dangerous electrical conductors or apparatus is a very good one, because it avoids the chance, which is very great, of making contacts with both hands and getting the current through the body. This rule is often made still more definite by saying, "Keep one hand in your pocket," in order to make sure not to use it. The above precautions are often totally disregarded, particularly by those who have become careless through familiarity with dangerous currents. The result has been that *almost all persons accidentally killed*

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* These articles should be subjected to tests at frequent intervals, so as to determine their condition.

by artificial electricity have been experienced linemen or station men.

Stopping Generators or Motors. This is accomplished by following substantially the same directions as for starting them, but in the reverse order.

A generator operating alone on a circuit can be slowed down and stopped without touching the switches, brushes, etc., in which case the current gradually decreases to zero; and then the connections can be opened without sparking or any other difficulty.

However, when a generator is operating in parallel with others, or with a storage battery, it must not be stopped or reduced in speed, until it is entirely disconnected from the system, otherwise it will act as a short circuit. Furthermore, the current generated by it should be reduced nearly to zero before its switch is opened. This is accomplished by adjusting the field rheostat of the machine to be cut out, great care being taken that the change is gradual. If the reduction be rapid, the voltage of the machine may drop so low as to cause a back current to flow.

A **constant-current generator** may be cut into or out of circuit in series with others, and can be slowed down or stopped; or its armature or field coils may be short-circuited to prevent the action of the machine, without disconnecting it from the circuit. *It is absolutely necessary, however, to preserve the continuity of the circuit,* and not to attempt to open it at any point, as this would produce a dangerous arc. Hence a by-path must be provided by closing the main circuit around the generator, before disconnecting it. This same rule applies to any lamp, motor, or other device on a constant-current system.

Never, except in an emergency, should any circuit be opened when heavily loaded, for the reason that the flash at the contact points, discharge of magnetism, and mechanical shock which result, are decidedly objectionable.

A Constant-Potential Motor is stopped by turning the starting-box handle back to the position it had before starting (Fig. 28); or, *if there is a switch Q, connecting the motor to the circuit,* as there always should be, it should be opened, after which the starting-box handle is moved back to be ready for starting again.

Immediately after a machine is stopped, it should be thoroughly cleaned, and put in condition for the next run. When not in use, machines should, when feasible, be protected from dirt and moisture by covers of some waterproof material.

INSPECTING AND TESTING.

Adjustment and the other points which depend merely upon mechanical construction, are hardly capable of being investigated by a regular quantitative test, but they can and should be determined by thorough inspection. In fact a very careful examination of all parts of a machine should always precede any test of it. This should be done for two reasons: first, to get the machine into proper condition for a fair test; and, second, to determine whether the materials and workmanship are of the best quality and satisfactory in every respect. A loose screw or connection might interfere with a good test; and a poorly fitting bearing, brush-holder, or other part might show that the machine was badly made.

If it is necessary to take the machine apart for cleaning or inspection, the greatest care should be exercised in marking, numbering, and placing the parts, in order to be sure to get them together exactly the same as before. In taking a machine apart or putting it together, only the minimum force should be used. Much force usually means that something wrong is being done. A wooden or rawhide mallet is preferable to an iron hammer, since it does not bruise or mar the parts. Usually screws, nuts, and other parts should be set up fairly tight, but not tight enough to run any risk of breaking or straining anything. Shaking or trying each screw or other part with a wrench or screw-driver, will show whether any of them are too loose or otherwise out of adjustment.

Friction. The friction of the bearings and brushes can be tested roughly by merely revolving the armature by hand, or slowly by power, and noting if it requires more than the normal amount of force. Excessive friction is quite easily distinguished, even by inexperienced persons. Another method is to revolve the armature by hand or otherwise, and see if it continues to revolve by itself freely for some time. A well-made machine in good condition and running at or near full speed, will continue to run for several minutes after the turning force is removed.

A method for actually measuring the friction consists in attaching a lever (a bar of wood, for example) to the shaft or pulley at right angles to it. The force required to overcome the friction and to turn the armature without current, is then determined by known weights or, more conveniently, by an ordinary spring balance. For convenience in dividing by the length of the lever, etc., to determine the value of the friction compared with the power of the machine, it should be exactly 1, 2, or 4 feet long. The friction of the bearings alone—that is, the pull which is required to turn the armature when the brushes are lifted off the commutator—should not exceed about 2 per cent of the total torque or turning force of the machine at full load. When the brushes are in contact with the commutator with the usual pressure, the friction should not then exceed about 3 per cent; that is, the brushes themselves should not consume more than 1 per cent of the total turning force.

Another method of measuring the friction of a machine is to run it by another machine used as a motor, and determine the volts and amperes required, first, with brushes lifted off, and second, with brushes on the commutator with the usual pressure. The torque or force exerted by the driving machine is afterwards measured by a Prony brake in the manner described hereafter for testing torque, care being taken to make the Prony brake measurements at exactly the same volts and amperes as were required in the friction tests. In this way the torques exerted by the driving machine to overcome friction in each of the first two tests are determined; and these torques, compared with the total torque of the machine being tested, should give percentages not exceeding those stated above for maximum values of friction. The magnetic pull of the field on the armature may be very great if the latter is not exactly in the center of the space between the pole pieces. This would have the effect of increasing the friction of the shaft in the bearings when the field is magnetized. It occurs to a certain extent in all cases, but it should be corrected if it becomes excessive. This may be tested by turning the current into the fields, being sure to leave the armature disconnected, and then turning the shaft with the lever as before. The friction in this case should not be more than 2 to 4 per cent.

Tests for friction alone should be made at a low speed, because at high speeds the effects of Foucault currents and hysteresis enter and materially increase the apparent friction.

Balance. The perfection of balance of the armature or pulley can be roughly tested by simply running the machine at normal speed and noting if these parts cause any objectionable vibration. Of course, practically every machine produces perceptible vibration when running, but this should not amount to more than a very slight trembling. The balance of a machine can be definitely tested, and the extent of the vibration measured, by suspending the machine or by mounting it on wheels, and running it at full speed. In this case it is better to run the machine as a motor, even though it be actually a generator, in order to avoid the necessity of running it by a belt, which would cause vibration and interfere with the test. If, however, the use of a belt is unavoidable, it should be arranged to run vertically upward or downward so as not to produce any horizontal motion in addition to the vibration of the machine itself. Fig. 40 shows a machine hung up to be tested for balance, and run either as a motor or by the vertical belt indicated by the dotted lines. Any lack of balance will cause the machine to vibrate or swing horizontally, and this motion can be measured on a fixed scale.

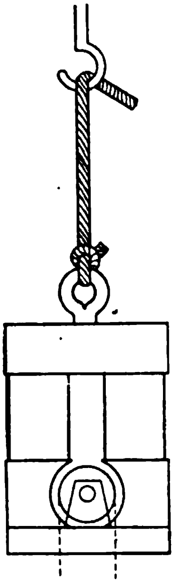


Fig. 40.

Noise. This cannot well be tested quantitatively, although it is very desirable that a machine should make as little noise as possible. Noise is produced by various causes. The machine should be run at full speed, and any noise and its cause carefully noted. A machine—especially the commutator—will nearly always run more quietly after it has been in use a week or more and has worn smooth.

Heating. The proper way to determine the temperature rise in electrical apparatus is by measurements of resistance, before and after operating for a specified time (usually 3 to 4 hours) under rated load.

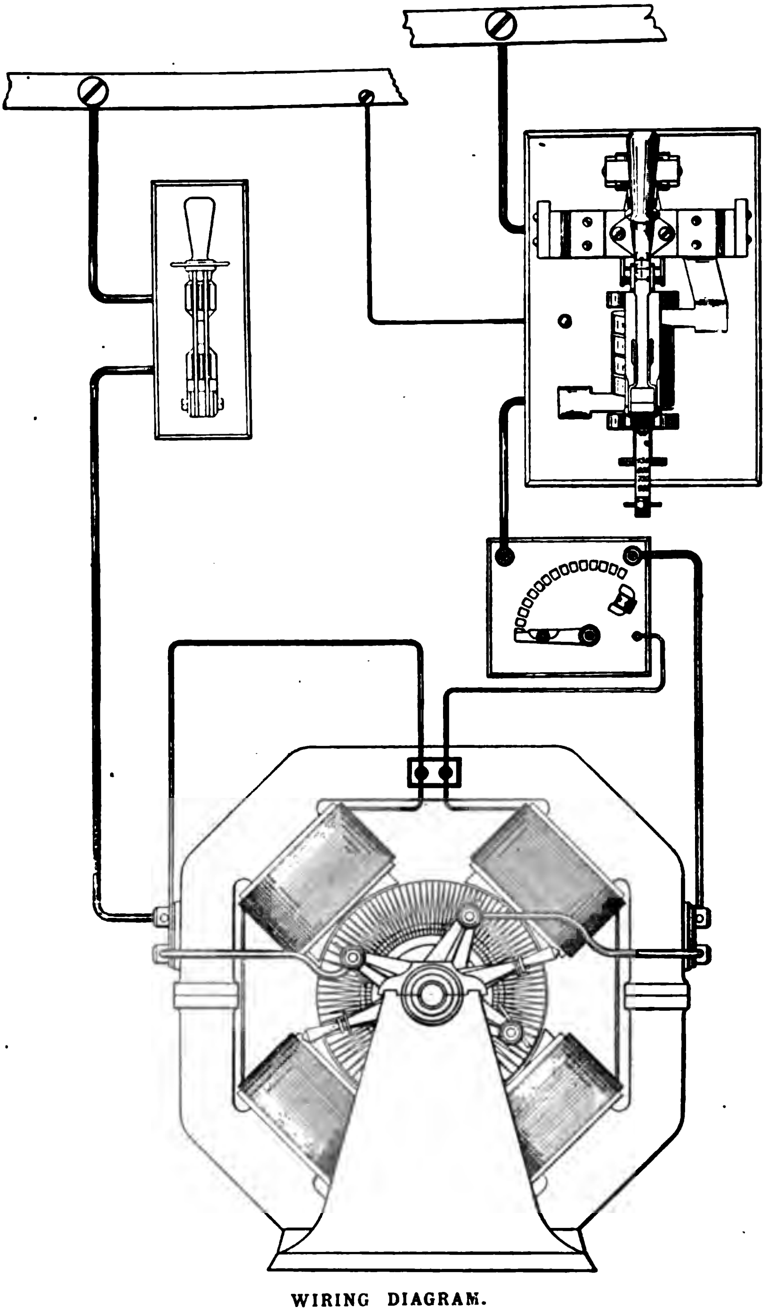
The rise of temperature is:

$$\theta = (238.1 + t)\left(\frac{(R_t + \theta}{R_t} - 1\right),$$

in which t is the room temperature in degrees Centigrade, R_t the resistance in ohms at room temperature, and $(R_t + \theta)$ the final resistance at a temperature elevation of θ° C. The standard room temperature is 25° C; and if it differs from this, the determined rise should be corrected by $+\frac{1}{2}$ per cent for each degree C. For ordinary tests it may be assumed that the resistance of copper increases .4 per cent for each degree C rise in temperature. The allowable rise in temperature for field or armature windings is 50° C, hence their resistance for continuous operation at rated load should not be more than 20 per cent in excess of the room temperature. The heating of commutators, collector rings, and brushes that cannot be measured electrically, is tested by thermometers when the machine is stopped, the permissible rise being 50° C; and for bearings and other parts of machines the limit is 40° C. When a thermometer is applied to a surface it should be covered by a pad of cotton or waste cloth, in a shallow, circular box about $1\frac{1}{2}$ inches in diameter. A large pad tends to accumulate heat. When machines are in operation, or in other cases when it is not convenient to measure resistances, especially for excessive temperatures due to abnormal conditions, thermometers may be used to test all stationary parts; but it should be noted that their indications are usually about 5° C lower than those determined by resistances, because the surface is cooler than the interior. A very simple test of heating is to apply the hand to the armature, etc., and if it can be held there without great discomfort, the temperature is not dangerous. Allowance should always be made, however, for the fact that, on account of its heat conductivity, bare metal feels very much hotter than cotton-covered wires, cloth, etc., at the same actual temperatures; but this apparent difference is much less if the hand is kept on for 10 to 20 seconds.

Sparking at the commutator cannot be accurately measured; but it is very objectionable, and in a machine in good order should be hardly perceptible. In any test one should observe carefully whether the sparking is excessive or not; and if so, to what it is due.

An approach to measurement may be made by starting with a lightly loaded machine and gradually increasing the load, meanwhile shifting the rocker-arm and brushes back and forth, and noting at what load it is impossible to find a non-sparking point. In machines the brushes must be shifted to follow the armature reaction as the load increases; but one should always be able to find a place where sparking ceases, within the rated load. In fact, a machine should be able to run with 25 per cent overload before sparking is serious. If a machine begins to spark at 50 per cent of its load, it is clearly only half as useful as it might be, and this may be taken in a sense as a measure of sparking.



WIRING DIAGRAM.

Connections of Single Pole Overload and no Voltage I-T-E Circuit Breaker.

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

PART II

ELECTRICAL RESISTANCE.

Among the most important tests which it is necessary to make in connection with Dynamo-Electric Machinery are those for resistance.

There are two principal classes of resistance tests that must be made in connection with generators and motors. First, the resistance of the wires or conductors themselves, called the *metallic* resistance; and, second, the resistance of the insulation of the wires, known as the *insulation* resistance. The latter should always be as high as possible, because a low insulation resistance not only allows current to leak, but also causes "burn-outs" and other accidents. Metallic resistance, such, for example, as the resistance of the armature or field coils, is commonly tested either by the Wheatstone bridge or by the "drop" (fall-of-potential) method.

The Wheatstone Bridge is simply a number of branch circuits connected as indicated in Fig. 41. A, B, and C are resistances the values of which are known. X is the resistance which is being measured. G is a galvanometer, S its key, and E is a battery of one or two cells controlled by a key K, all being connected as shown. The resistance C is varied until the galvanometer shows no deflection, when the keys K and S are closed in the order named. If the key S should be closed before K, or at the same moment, the

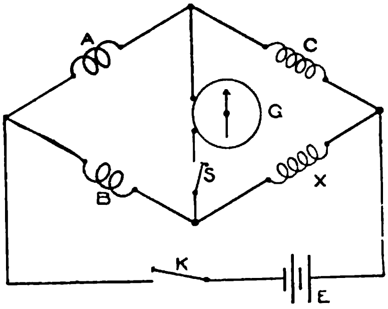


Fig. 41.

inductive effect would produce a pronounced deflection of the galvanometer needle, and thus probably cause confusion. The value of the resistance X is then found by multiplying together resistances C and B, and dividing by A; that is,

$$X = \frac{C \times B}{A}.$$

A very convenient form of this apparatus is what is known as the portable bridge (Fig. 42). This consists of a box containing the three sets of known resistances, A, B, and C, controlled by plugs; also the galvanometer G, and keys K and S, all connected in the proper way. In some cases further convenience is secured by including the battery E in the box; but ordinarily this is not done, and it is necessary to connect one or two cells of battery to a pair of binding-posts placed on the box for that purpose. Resistances from $\frac{1}{10}$ ohm to 100,000 ohms can be conveniently and accurately measured by the Wheatstone bridge. Below $\frac{1}{10}$ ohm the resistances of the contacts in the binding-posts and plugs are apt to cause errors, and therefore special bridges provided with mercury contact cups are used. In fact, in measuring any resistance, care should be taken to make the connections clean and tight.

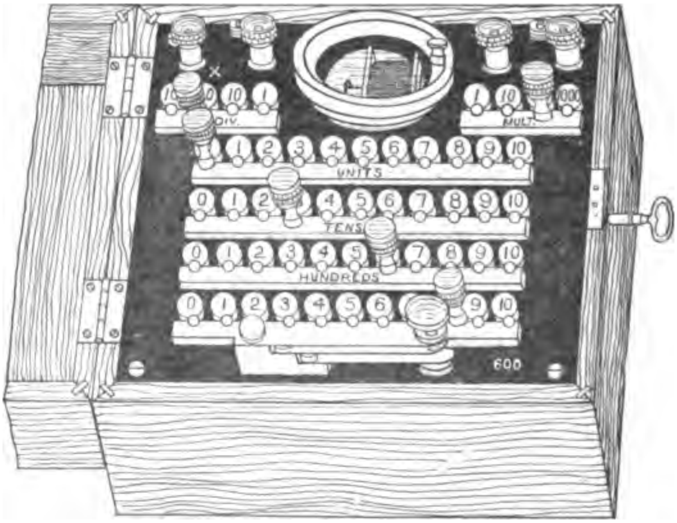


Fig. 42.

The ordinary bridge will not measure above 100,000 ohms, because, if the resistance in the arm B is 100 ohms, 1 ohm in A, and 1,000 ohms in C, then X is 100,000. Sometimes the arms A and B are provided with 1,000-ohm coils in addition to the usual 1-, 10- and 100-ohm coils; or sometimes the arm C contains more than 1,000 ohms in all; in either case the range will be correspondingly increased.

It should be observed, however, that the use of ratios of 1,000: 1, or even 100: 1, is not desirable, since they are likely to multiply any error due to contact resistances, etc. In fact, it is usually better to have the four resistances not very widely different in value; that is, no one of them should be more than ten times greater than any other except when very high or very low resistances are to be measured. The Wheatstone bridge may be used for testing the resistances of almost any field coils that are found in practice. Shunt fields for 110-volt machines usually vary from about 100 or 200 ohms in a 1-H. P. machine to about 5 to 20 ohms in a 100-H. P. machine. If the voltage is higher or lower than 110, these resistances vary as the square of the voltage. Series fields for arc-circuit dynamos vary from about 1 to 20 ohms. In measuring field resistances with the bridge, care must be taken to wait a considerable time after pressing the battery key, before pressing the galvanometer key, in order to allow time for the self-induction of the magnets to disappear.

The bridge may be used also for testing the armature resistance of some machines. But 110-volt shunt machines above 10 H. P. usually have resistances less than $\frac{1}{10}$ ohm, which is below the range of the ordinary bridge, as already stated. For higher or lower voltages the resistance is proportional to the square of the voltage. Arc machines have armatures of about 1 to 20 ohms resistance, and are therefore easily tested by the bridge.

The Drop (or **Fall-of-Potential**) **Method** is well adapted for locating faults quickly, and for testing the armature resistance of most generators and motors, or the resistance of contact between commutator and brushes, or other resistances which are usually only a few hundredths or even thousandths of an ohm. This consists in passing a current through the armature and connections and a known resistance (of, say, $\frac{1}{100}$ ohm), all connected in series, as represented in Fig. 43. The "drop" or fall of potential in the armature and that in the known resistance are compared by connecting a voltmeter first to the terminals of the known resistance (marked 1 and 2), and then to various other points on the circuit, as indicated by the dotted voltmeter terminals at M, N, O, Q, R, and S, so as to include successively each part to be tested. The deflections in all cases are directly proportional to the resistances included between the points touched by the terminals. The current needed depends upon the resistance of the circuit and the sensitiveness of the voltmeter. A bank of lamps or a liquid resistance is used for limiting the current. Instead of using a known resistance, an ammeter may be inserted in series with the resistance to be tested, the latter being then determined by Ohm's law, *viz.*, If E is the voltmeter deflection, and I represents the amperes flowing, the resistance of the part under test is $R = \frac{E}{I}$

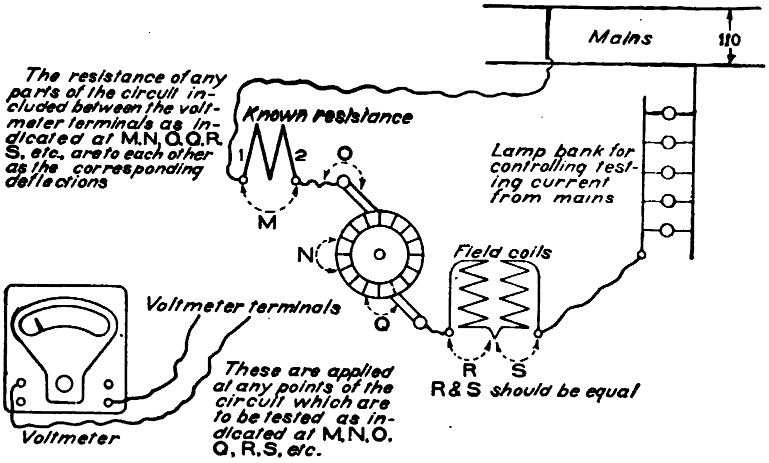
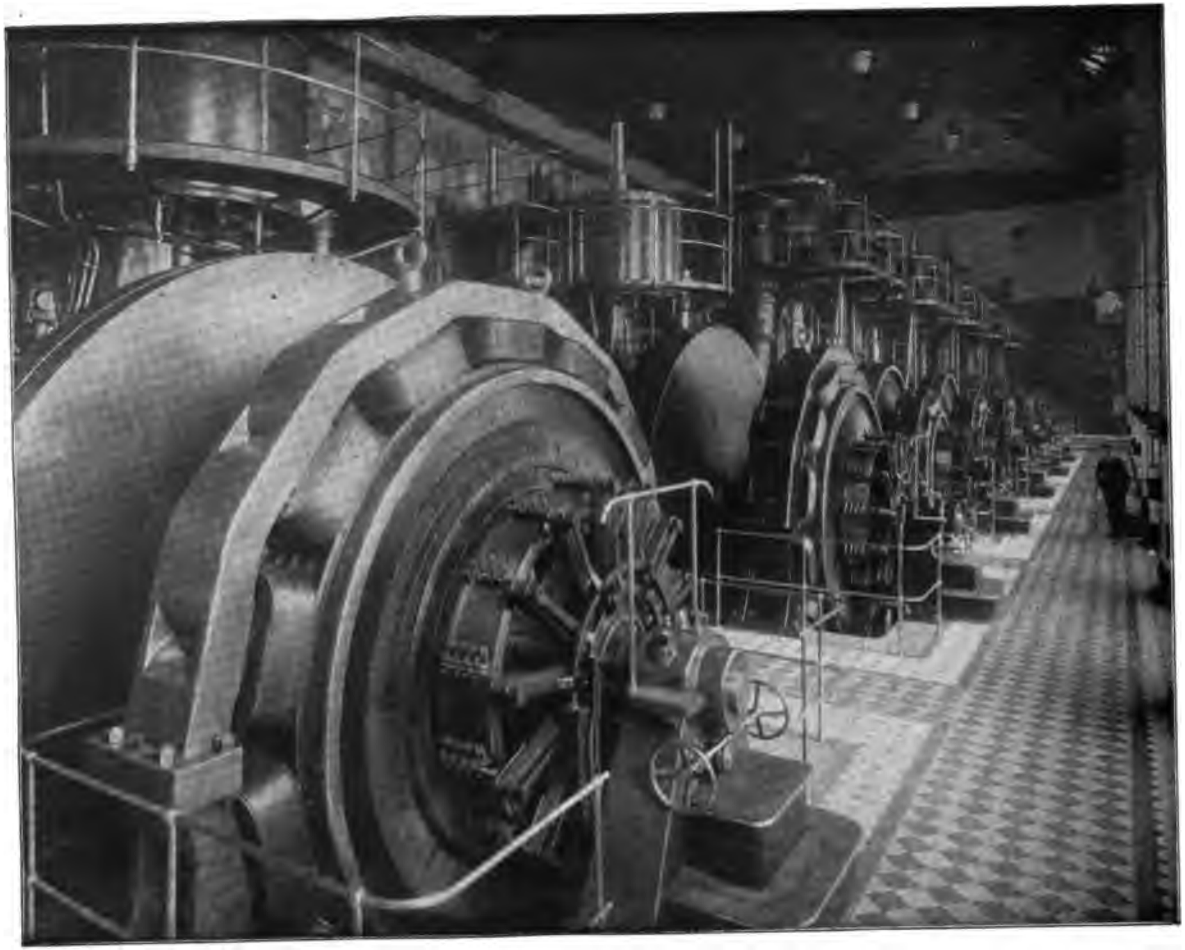

The resistance of any parts of the circuit included between the voltmeter terminals as indicated at M.N.O.Q.R. S. etc., are to each other as the corresponding deflections
Mains
110
Known resistance
1
2
O
M
N
Q
Lamp bank for controlling testing current from mains
Field coils
Voltmeter terminals
These are applied at any points of the circuit which are to be tested as indicated at M.N.O. Q. R. S. etc.
R
S
R & S should be equal
Voltmeter

Fig. 43.

A "station" or a portable voltmeter may be used for the readings, and its terminals may be held in the hands, or they may be conveniently arranged to project from an insulating handle like a two-pronged fork. Usually 10 to 100 amperes and a low-reading voltmeter are needed for low resistances.

It is well to start with a small testing current, and increase it until a good deflection is obtained on the voltmeter. If a current



Hamburg Central Power Station

Hamburg, Germany

of several amperes cannot be had, a few cells of storage battery or some strong primary battery, such as a Bunsen, bichromate, or plunge battery, can be used with a galvanometer or low-reading voltmeter.

The diagram indicates the testing of a machine with series fields. Shunt fields must be connected directly to the line on account of their high resistance; while the armature can be connected as here shown, without being allowed to revolve.

This drop method of testing is also very useful in locating any fault. The two wires leading from the voltmeter are applied to any two points of the circuit, as indicated by the dotted lines —for instance, to two adjacent commutator segments, or to a brush tip and the commutator; any break or poor contact will be indicated immediately by the deflection being larger than at some other similar part. This shows that the fault is between the two points to which the wires are applied. Thus, by moving these along on the circuit, the exact location of any irregularity, such as a bad contact, short circuit, or extra resistance, can be found.

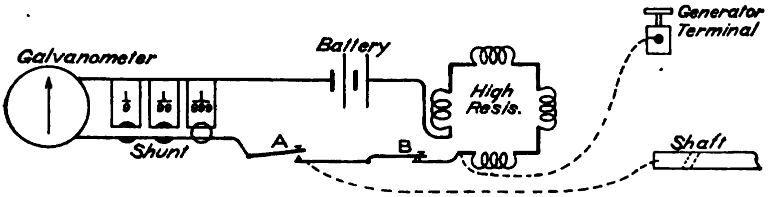


Fig. 44.

The *insulation resistance* of a generator or motor, that is, the resistance between its wires and its frame, should be sufficiently high so that not more than one-millionth of its rated current will pass through it at normal voltage, and it is well to have it still higher. It is therefore beyond the range of ordinary Wheatstone-bridge tests; but two good methods are applicable—the "direct-deflection" and the voltmeter method.

The Direct-Deflection Method is carried out by connecting a sensitive galvanometer, such as a Thomson high-resistance reflecting galvanometer, in series with a known high resistance, usually a 100,000-ohm rheostat, a battery, and keys, as shown in Fig. 44 The galvanometer should be shunted with the $\frac{1}{999}$ coil of the shunt, so that only $\frac{1}{1000}$ of the current passes through the galvanometer, the machine being entirely disconnected. The keys A and B are closed and the steady deflection noted. It is well to use but one cell of the battery at first, and then increase the number if necessary until a considerable deflection is obtained. The circuit is then opened at the key B, and connected by wires to the binding-post or commutator and to the frame or shaft of the machine, as indicated by dotted lines, so that the machine insulation resistance is included directly in the circuit with the galvanometer and battery. The key A is then closed and the deflection noted. Probably there will be little or no deflection, on account of the high insulation resistance; and the shunt is changed to $\frac{1}{99}$, $\frac{1}{9}$, or left out entirely if little deflection is obtained. In changing the shunt, the key should always be open, otherwise the full current is thrown on the galvanometer. The insulation is then calculated by the formula:

$$\text{Insulation resistance} = \frac{D \times R \times S}{d},$$

in which D is the first deflection without the machine being connected, and d the deflection with the machine insulation in the circuit, R the known high resistance, and S the ratio of the shunt. That is, if the shunt is $\frac{1}{999}$ in the first test, and $\frac{1}{9}$ in the second, then S is 100; and if the shunt is out entirely in the second test, S is 1,000. It is safer to leave the high resistance in circuit in the second test, to protect the galvanometer in case the insulation resistance is low. Therefore this resistance must be subtracted from the result to obtain the insulation of the machine itself.

By the above method it is possible to measure 100 megohms or even more. The wires and connections should be carefully arranged to avoid any possibility of contact or leakage, which would spoil the test. If no deflection is obtained, place one finger on the frame and one on the binding-post of the machine, which makes enough leakage to affect the galvanometer and show that the connections are right, thus proving that any poor insulation will be indicated if it exists.

The Voltmeter Test for Insulation Resistance requires a sensitive high-resistance voltmeter, such as the Weston. Take, for example, the 150-volt instrument, Fig. 45, which usually has about 15,000 ohms resistance. (A certificate of the exact resistance is pasted inside each case.) Apply it to some circuit or battery, and measure the voltage. This should be as high as possible—say, 100 volts. The insulation resistance of the machine is then connected into the circuit, as indicated in Fig. 46. The deflection of the voltmeter is less than before, in proportion to the value of the insulation resistance.

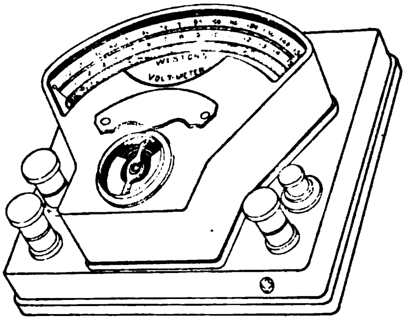


Fig. 45.

The insulation is then found by the equation:

$$\text{Insulation resistance} = \frac{D \times R}{d} - R,$$

in which D is the first and *d* the second deflection, and R the resistance of the voltmeter. If the circuit is 100 volts, D is 100; and if *d*, the deflection through the insulation resistance of the machine, is 1 division, the insulation is 1,485,000 ohms. Permanent marks indicating amounts of insulation may be put on the voltmeter scale. When making measurements, the voltage should be the same as that employed in preparing this scale (say, 115 volts). To calculate the scale use this formula:

$$d = \frac{115\,R}{X + R},$$

in which X is the insulation resistance (1 megohm, ½ megohm, etc.), and *d* is the number of volts, opposite which the corresponding graduation is to be placed to form the new scale. This method does not test very high resistances; but if little or no deflection is obtained through the insulation resistance, it shows that the latter is at least several megohms—which is high enough for most practical purposes.

The ordinary magneto-electric bell may be used to test insulation by simply connecting one terminal to the binding-post of the machine, and the other to the frame or shaft.

A magneto bell is rated to ring from 10,000 to 30,000 ohms; and if it does not ring, it shows that the insulation is more than that amount. This limit is altogether too low for proper insulation in any case; and therefore this test is rough, and really shows only whether or not the insulation is very poor or the machine actually grounded.

The magneto is also used for "continuity" tests, to determine whether a circuit is complete, by simply connecting the two terminals of the magneto to those of the circuit. If the bell can be rung, it shows that the circuit is complete; if not, it indicates a break. An ordinary electric bell and cell of battery can be used in place of the magneto.

The insulation of a machine should always be tested for disruptive strength, with a current of at least double the normal working pressure, to see if it will "break down" or be punctured by the current. A transformer motor-dynamo wound to give high voltage is convenient for this.

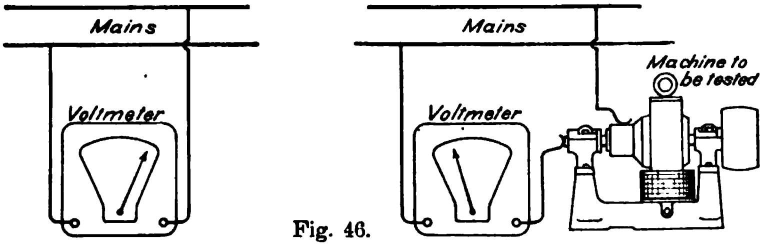


Fig. 46.

Tests of the resistances of generators or motors should properly be made when the machines are as warm as they get when running continuously at full load. This increases the resistance of conductors and decreases the insulation resistance, but it gives the actual working values.

Voltage. Instruments for measuring voltage (known as voltmeters) are in nearly all cases galvanometers of practically constant resistance. Through them flow currents which are directly proportional to the impressed voltages. A pointer connected to the moving part deflects over a graduated scale. A voltmeter should have as high a resistance as possible—at least several thousand ohms—in order not to take too much current, which might lower its reading on high-resistance circuit or consume too much power. It should not be affected by the magnetism of a generator or motor at any distance over a few feet.

The voltage of any machine or circuit is tested by merely connecting the two binding-posts or terminals of the voltmeter to the two terminals or conductors of the machine or circuit. To get the external voltage of a generator or motor, the voltmeter is usually applied to the two main binding-posts or brushes of the machine. This external voltage is what a generator supplies to the circuit. It is also called the pole difference of potential or terminal voltage, and is the actual figure upon which calculations of the efficiency, capacity, etc., of any machine are based.

A generator for constant-potential circuits should, of course, give as nearly as possible a constant voltage. A plain shunt machine usually falls from 5 to 15 per cent in voltage when its current is varied from nothing to full load. This is due to the I R drop caused by the resistance of the armature circuit, which in turn weakens the field current and magnetism; armature reaction usually occurs also, and still further lowers the external voltage. This variation is undesirable, and is usually avoided by regulating the field magnetism (varying the resistance in the field circuit) or by the use of compound-wound generators. A compound-wound dynamo should not fall appreciably from no load to full load; in fact, if it is "over-compounded" it should rise 5 per cent or more in voltage to make up for loss on the wiring.

The voltage of a constant-current generator is not important. The current should be carefully measured by an ammeter, but little attention is paid to the voltage in practical working; in fact, it changes constantly with variations in the load. But it is necessary, of course, to measure it in making efficiency or other exact tests.

A simple and fairly accurate method of measuring voltage is by means of ordinary incandescent lamps. A little practice enables one to tell whether a lamp has its proper voltage and brightness. In this way it is easy to tell if the voltage is even one or two per cent above or below the normal point. Voltages less than the ordinary can be tested by using low-voltage lamps or by estimating the brightness of high-voltage lamps. For example, a lamp begins to show a very dull red at one-third and a bright red at one-half its full voltage. Voltages higher than that of one lamp can be tested by using lamps in series. Thus 1,000 volts can be measured by using 10 lamps in series, and so on.

Current. This is measured by an ammeter (Fig. 47), which is usually cheaper than a voltmeter because it contains a comparatively small amount of wire. In testing the current of a generator or motor, it is necessary only to connect an ammeter, of the proper range, in series with the machine to be tested, so that the whole current passes through the instrument or its shunt. To test the current in the armature or the field alone, the ammeter is connected in series with the particular part. To avoid mistakes in the case of a shunt-wound generator, it is well to open the external circuit entirely in testing the current used in the field coils; for the same reason the brushes of a shunt motor should be raised before testing the current taken by the field.* In a constant-current or series-wound dynamo, the same current flows through all parts of the machine and the circuit; consequently the measurement of current is very simple.

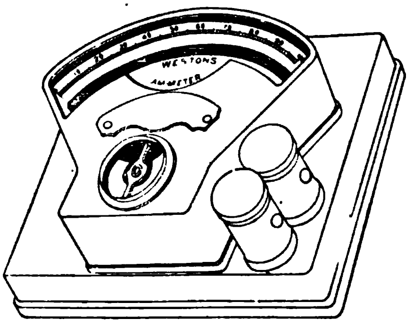


Fig. 47.

If an ammeter cannot be had, current can be measured by inserting a known resistance in the circuit and measuring the difference of potential between its ends. The volts thus indicated, divided by the resistance in ohms, gives the number of amperes flowing. If a known resistance is not at hand, the resistance of a part of the wire forming the circuit can be obtained from its diameter measured with a screw caliper or a wire gauge, by referring to any of the tables of resistances of wires; or the resistance can be measured by a Wheatstone bridge (Fig. 42), or by putting an ammeter, when one can be spared, into the circuit, while the voltmeter is connected. The volts divided by the amperes gives the resistance in ohms between the points to which the voltmeter is connected. Two connections can be attached permanently to two points on the circuit, and an ammeter temporarily inserted, and for every reading of the ammeter the corresponding reading of the voltmeter attached to these connections may be noted. Then, by keeping a list of these readings, the amperes can be found at any future time, by connecting the voltmeter to the two permanent contacts. This preliminary use of the ammeter amounts to measuring the resistance between the two contacts, and allows for the increase of resistance when the current and heating increase. In any case it is convenient to use a length of wire, or a distance between contacts, which will give an even amount of resistance, say, 1-10 or 1-100 ohm. And, as with large current the resistance will be fractional, care must be taken to avoid errors in multiplying, etc.

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* These instructions are to be followed when only one ammeter is to be had; otherwise one could be placed in the field circuit, and another in the circuit from the starting box to the independent armature terminal.

In testing the output of a generator, it is often quite a problem to dispose of the current produced. A bank of lamps, for example, to use the whole current generated by a dynamo of 110 volts and 1,000 amperes, would be very expensive. A sufficient number of resistance-boxes for the purpose would also be very costly. The best way is to drive the generator by a motor, and connect it up in parallel with the line. In this way most of the power is returned instead of being wasted. If a motor cannot be had, the simplest and cheapest way to consume a large current is to place two plates of iron in a common tub or trough filled with a weak solution of carbonate of soda (common washing soda), which is better than almost any other solution because it neither gives off fumes nor eats the electrodes. The main conductors are connected to the two plates, respectively, and the current passes through the solution. The resistance and current are regulated by varying the distance between the plates, the depth they are immersed in the liquid, and the strength of the solution. The energy may be suf-

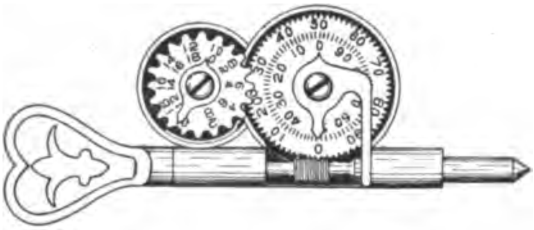

Fig. 48.

ficient to boil the liquid, but this does no harm. Three to ten amperes per square inch of active surface of plate may be allowed.

Speed. This is usually measured by the well-known **speed counter** (Fig. 48), consisting of a small spindle which turns a wheel one tooth each time it revolves. The point of the spindle is held against the center of the shaft of the generator or motor for a certain time, say, one minute or one-half minute, and the number of revolutions is read off from the position of the wheel.

Another instrument for testing the number of revolutions per minute is the **tachometer.** The stationary form of this instrument is shown in Fig. 49. It must be belted by a string, tape, or light leather belt to the machine the speed of which is to be tested. If the sizes of the pulleys are not the same, their speeds are inversely proportional to their diameters. The portable form of this instrument (Fig. 50) is applied directly to the end of the shaft of the machine, like the speed counter. The tip can be slipped upon either one of the three spindles, which are geared together, according as the speed is near 500, 1,000, or 2,000 revolutions. These instruments possess the great advantage over the speed counter that they instantly point on the dial to the proper speed, and they do not require to be timed for a certain period.

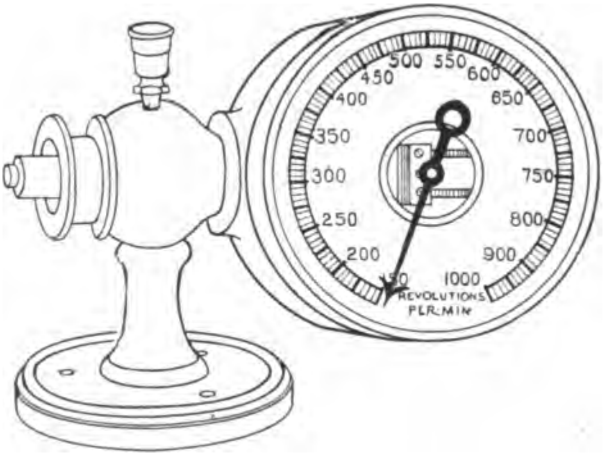

Fig. 49.

A simple way to test the speed in revolutions per minute is to make a large black or white mark on the belt of a machine, and note how many times the mark passes per minute; the length of the belt divided by the circumference of the pulley gives the number of revolutions of the pulley for each time the mark passes. The number of revolutions of the pulley to one of the belt can also be easily determined by slowly turning the pulley or pulling the belt until the latter makes one complete trip around, at the same time counting the revolutions of the pulley. If the machine has no belt, it can be supplied with one temporarily for the purpose of the test, a piece of tape with a knot or an ink mark being sufficient. Care should be taken in all these tests of speed with belts not to allow any slip; for example, in the case of the tape belt just referred to, this belt should pass around the pulley of the machine and some light wheel of wood or metal which turns so easily as not to cause any slip of the belt on the pulley of the machine.

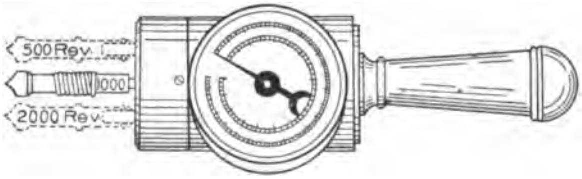

Fig. 50.

Torque or **Pull** is measured in the case of a motor by the use of a Prony brake. This consists of a lever LL of wood, clamped on the pulley of the machine to be tested, as indicated in Fig 51. The pressure of the screws SS is then adjusted by the wing-nuts until the friction of the clamp on the pulley is sufficient to cause the motor to take a given current, and the speed is then noted. Usually, the maximum torque or pull is the most important to test; and this is obtained in the case of a constant-potential motor by tightening the screws SS until the motor draws its full current as indicated by an ammeter. What the full current should be, is usually marked on the name-plate; if not, it may be assumed to be about 8 amperes per H. P. for 110-volt motors, 4 amperes per H. P. for 220-volt, and 1 3-4 amperes per H. P. for 500-volt motors. If the machine is rated in kilowatts, the full current in amperes can be found by multiplying by 1,000 and dividing by the voltage of the machine. The torque or pull is measured by known weights, or more conveniently by a spring balance P. I desired, the test may also be made at three-quarters, one-half, or any other fraction of the full current.

The torque or pull in pounds which should be obtained, can also be calculated from the power at which the machine is rated, by the formula ;

$$\text{Torque} = \frac{\text{H. P.} \times 33{,}000}{6.28 \times \text{S}},$$

in which H. P. is the horse-power of the machine at full load, and S is the speed of the machine in revolutions per minute at full load. Torque is given at unit radius, commonly pounds at one foot. The pull at any other radius is converted into torque by multiplying by the radius; 1, 2, and 4 ft. are convenient radii or lengths of lever for measuring pull. One H. P. produced at a speed of 1,000 revolutions requires a pull of 5.25 pounds at end of 1-foot lever; at 500 revolutions, twice as much; at 2,000 revolutions half as much; and so on. If the lever is 4 feet, the pull is one-fourth as much, etc.

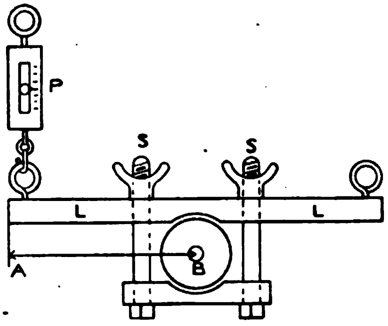

Fig. 51.

The Torque of a Generator, that is, the power required to drive it, is very conveniently determined by operating it as a motor, and testing it by the Prony brake as described above, the torque of a generator being practically equal to that of a motor under similar conditions.

Power. The electrical power of a generator or motor is found by testing the voltage and current at the terminals of the machine, as already described, and multiplying the two together, which gives the electrical power of the machine in watts.* Watts are converted into horse-power by dividing by 746, and into kilowatts by dividing by 1,000.

The mechanical power of a generator or motor, that is, the power required for or developed by it, is found by multiplying its pull by its speed and by the circumference on which the pull is measured, and dividing by 33,000. That is,

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*In testing an alternating-current machine, a wattmeter should be employed instead of a voltmeter and an ammeter, as explained later.

$$\text{Horse-power} = \frac{P \times S \times 6.28 \times R}{33,000},$$

in which P is the pull in pounds, S the speed in revolutions per minute, and R the radius in feet at which P is measured.

Efficiency. This is determined in the case of a generator by dividing the electrical power generated by it by the mechanical power required to drive it; that is,

$$\text{Efficiency of generator} = \frac{\text{Electrical power}}{\text{Mechanical power}}.$$

The efficiency of a motor is the mechanical power developed by it, divided by the electrical power supplied to it; that is,

$$\text{Efficiency of motor} = \frac{\text{Mechanical power}}{\text{Electrical power}}.$$

These are the **actual** or **commercial efficiencies** of these machines, and should be at least 90 per cent at rated load in machines of 10 H. P. and over.

The so-called "electrical efficiency" is misleading and of little practical importance, and should not be considered in commercial work. The mechanical and electrical power in the above equations are determined as already explained.

It is usually more convenient to test the efficiency of a generator by testing it as a motor with a Prony brake. But the efficiency of a generator may be determined very easily by driving it with a calibrated electric motor, that is, one in which the power developed for any given number of volts and amperes consumed is known. Then it is only necessary to measure the watts supplied by the generator when the motor is running at a certain power, and the efficiency of the generator is *the watts ÷ the known power*.

Another method is to employ two identical machines, one used as a motor driving the other as a generator. The shafts of the two machines should be directly connected by some form of coupling; a belt may be used, but its friction would cause a small loss. The watts produced by the generator, divided by the watts consumed by the motor, is the combined efficiency of the two machines; and the efficiency of each is the square root of that fraction. For example, if the combined efficiency is .81, then that of each machine is .90, since .90 × .90 = .81. This assumes that the two efficiencies are equal, which is sufficiently correct if the machines are exactly alike. The current from the generator may be used to help feed the motor, and then only the difference in current need be supplied. This latter current represents the inefficiency or losses from friction, etc., in both machines.

To test in this way, connect both machines in parallel with the source of current; couple or belt them together; and then weaken the field, or shift the brushes of the machine which is to be used as a motor, so that it will speed up and drive the other as a dynamo, or cause it to drive the other by putting a large pulley on it. In this way the motor will consume current from the circuit while the generator yields current to the circuit. Both currents are measured and the efficiencies calculated.

The efficiency of a motor-generator or ordinary converter is very easily determined by simply measuring the input and output in watts (by wattmeters or by ammeters and voltmeters for direct currents), and dividing the latter by the former.

These electrical methods of testing are preferable to mechanical, for the reason that the volts and amperes can be easily and accurately measured, and their product gives the power in watts.* Mechanical measurements of power by dynamometer or other means are difficult, and usually not very accurate.

Separation of Losses. The total losses in a generator or motor, except that caused by the electrical resistance of the armature when carrying the full current, can be closely determined at once by noting the current required to run the machine free as a motor. In a machine of 90 per cent efficiency, this should not amount to more than about 8 per cent of the current required to give rated power. Consequently the easiest way to test a machine is to run it as a motor without load.

The various losses of power that occur in a generator or motor may be determined and separated from each other as follows:

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* When alternating-current machinery is being tested use wattmeters

Take a generator, for example, and drive it with another machine used as a motor in the manner described for testing friction. The motor should previously be calibrated, that is, tested to determine the exact mechanical power it develops for each amount of electrical power in watts supplied to it, as described for testing efficiency. A simple, shunt-wound motor on a constant-potential circuit is best suited to the purpose. The generator is first driven at normal speed with no field magnetism and with the brushes lifted; then the actual power developed by the motor equals the power lost in the generator by the friction of bearings and belt. The brushes are then adjusted in contact with the commutator, with the usual pressure. The increase in the power of the motor is equal to the brush friction.

Finally, excite the field magnet to full strength, and the increase in the power exerted by the motor is equal to the combined losses due to the Foucault or eddy currents and hysteresis in the iron core of the armature, provided there is no considerable side pull on the armature. The power wasted in Foucault currents varies as the square of the speed, while the hysteretic loss is only directly proportional to speed; hence the two may be separated by testing the machine at different speeds.

For example, let us call x and y the losses due to hysteresis and Foucault currents, respectively, at full speed; A the power consumed by both at full speed; and B the power consumed at half speed. Then $A = x + y$, and $B = \frac{x}{2} + \frac{y}{4}$; hence, by eliminating x, we have $y = 2A - 4B$. That is the Foucault loss is twice the power consumed by both at full speed minus four times the power consumed by both at half speed. The hysteresis loss $= A - y$. If eddy currents are developed in the copper conductors of the armature, they will increase the apparent Foucault loss as determined by the above test, since they also vary as the square of the speed. The power wasted by eddy currents might be found by testing the armature without any conductors upon it. This could be done only before the armature is wound or by unwinding it, neither of which is practicable except in the place where it is made. Ordinarily, however, eddy currents in the conductors do not amount to much unless they are very large, and even then the use of stranded conductors or conductors embedded in slots in the iron core largely overcomes the trouble.

Friction of the air might also increase the apparent Foucault loss; but it usually causes only a very small loss, and is almost impossible to separate except by running the machine in a vacuum, which is, of course, impracticable. The other losses are quite easily measured and separated, as follows:

The number of watts used in the field can be measured by a voltmeter and ammeter, or it can be calculated by the formula: Watts $= \frac{E^2}{R} = I^2R = EI$, in which E is the voltage, R the resistance, and I the current. It is sufficient if any of these two quantities are known. The loss in the armature conductors, due to ohmic resistance is found by multiplying the square of the current in the armature at full load by the armature resistance; in fact, this is usually called the "I^2R loss." This should not be more than 1 to 3 per cent in a constant-potential generator or motor, whether it be alternating or direct-current. The sum of all the losses make up the difference between the total power consumed by the machine and the useful power that it develops.

The ordinary values of the various losses in a good generator or motor of 25 H. P. are approximately as follows:

Useful power developed	about 92	per cent.
Used in magnetizing field	about 1 to 2	"
Loss in armature resistance (I^2R)	" 1 to 2	"
Friction of bearings	about 2	"
Friction of brushes	" ½	"
Friction of air	" ½	"
Hysteresis in armature core	" 1½	"
Foucault currents in armature core	" 1½	"

Measurement of Power in A. C. Circuits. In circuits carrying alternating currents and having some inductive load either in the form of motors or arc lamps or a partly loaded transformer, etc., the ordinary method of determining the power, by voltmeter and ammeter measurements, is not applicable, as the current is seldom in phase with the E. M. F., and therefore the product *volts* × *amperes* is not the true power.

There are several means for determining the true power of an A. C. circuit, the simplest being an indicating wattmeter. A wattmeter is an electro-dynamometer provided with two coils, a fixed one of coarse wire, the other movable and of fine wire. This movable coil is connected in series with a large non-inductive resistance, so that the time-constant of the fine-wire circuit is extremely small; and hence its impedance is practically equal to its resistance; the current in, and resulting field of, the fine-wire coil will under these conditions be practically in phase with the potential difference across its terminals. The field produced by the coarse-wire coil is directly proportional to the current flowing through it at any instant. Hence, the couple acting on the fine-wire coil is proportional at a given instant to the product of these fields; so that the reading of the instrument, which depends on the mean value of the couple, will be proportional to the mean power, and, by providing the instrument with the proper scale, it can be made to read directly in watts.

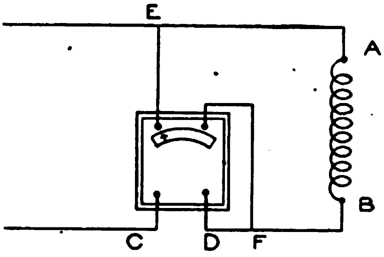

Fig. 52.

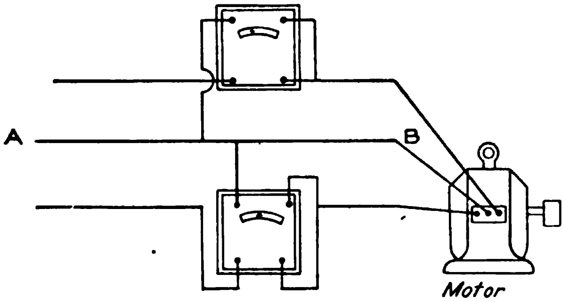

Fig. 53.

In Fig. 52, A B represents an inductive load—say, a single-phase motor—of which the power input is to be determined; C D the terminals of the thick-wire coil (current-coil) of the wattmeter; and E F the pressure-coil terminals. When connected as above indicated, the wattmeter indicates directly the power in watts supplied. In the case of a two-phase system, where the two circuits are independent, the power may be measured by placing a wattmeter in each phase, as shown in Fig. 52, and adding the two readings. If the motor be connected up as shown in Fig. 53,* where A B forms a common return, the wattmeters are placed as indicated, *care being taken to place the current-coils in the outside mains;* and the power supplied is equal to the sum of the two wattmeter readings.

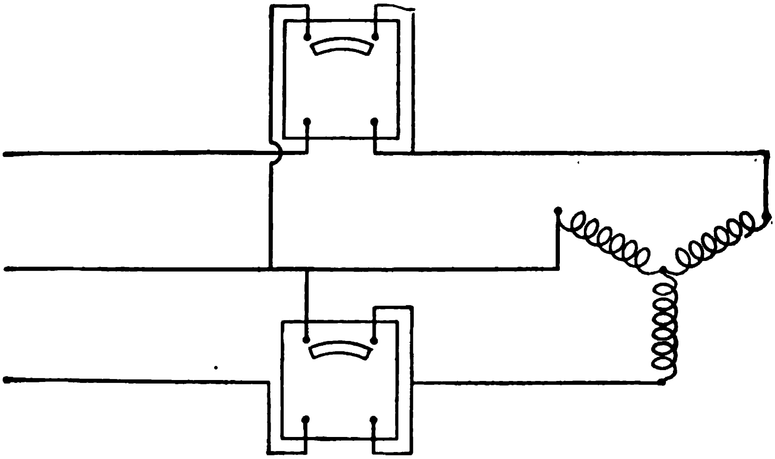

Fig. 54*a*.

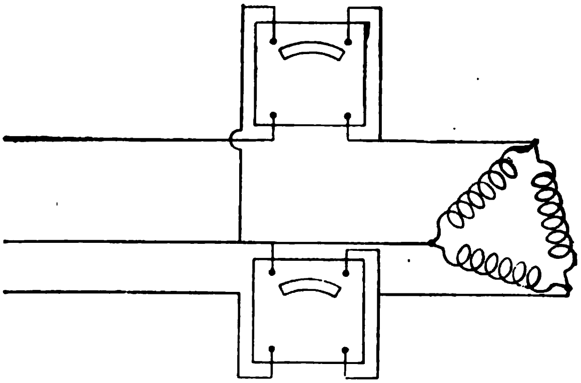

Fig. 54*b*.

The power of a balanced or unbalanced three-phase system can be determined by the use of two wattmeters connected as

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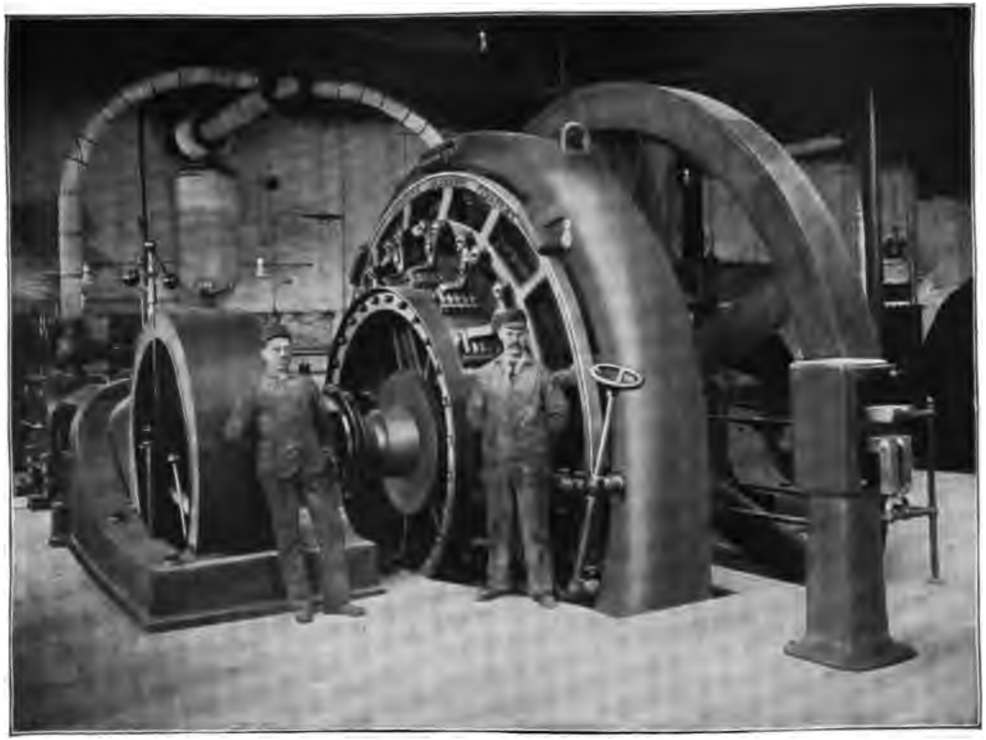
* This form of connection is possible only when the generator has two independent windings, one for each phase.



800 K.W. GENERATOR, 250 VOLTS, 80 R.P.M.

Western Electric Company.

shown in Fig. 54, *a* and *b*. The current-carrying coils are placed in series with two of the wires, and the pressure-coil respectively connected between these two mains and the third wire. The *algebraic* sum of these two wattmeter readings gives the true power supplied. When the power factor of the system is less than .5, one of the wattmeters will read negatively It is sometimes difficult to determine whether the smaller readings are negative or not. If in doubt, give the wattmeter a separate load of incandescent lamps, and make the connections such that both instruments deflect properly; then reconnect them to the load to be measured. If the terminals of one instrument have to be reversed, the readings of that wattmeter are negative.

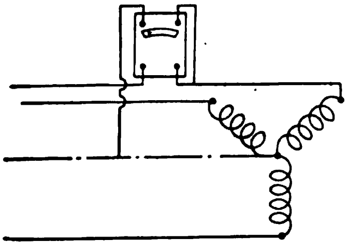


Fig. 55.

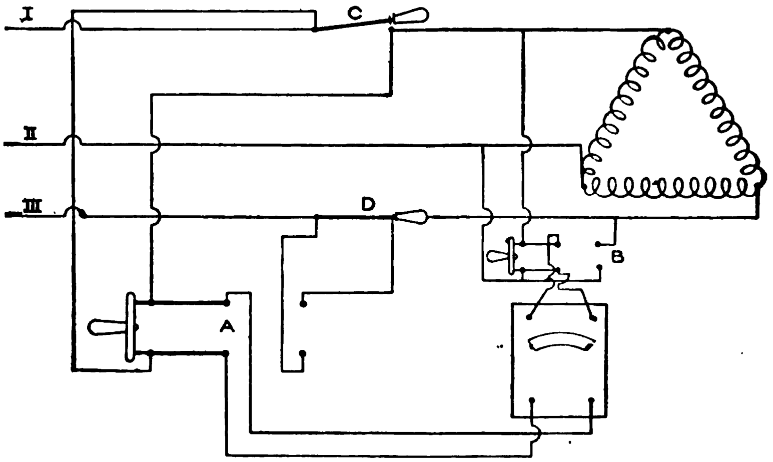


Fig. 56.

To measure the power of a balanced 4-wire 3 phase system, one wattmeter may be connected as shown in Fig. 55, and the wattmeter reading multiplied by 3. Usually, however, a 4-wire 3-phase system is unbalanced; and to determine the power supplied under this condition, three wattmeters should be employed, one for each phase, the power supplied being equal to the algebraic sum of all three readings.

It is obvious that in any of the above instances one wattmeter could be employed, provided the necessary switches are furnished. Assuming, for example, the 3-phase 3-wire case, one wattmeter would require switch connections as shown in Fig. 56. A is a double-pole switch, which, when thrown to the left, places the current-coil of the wattmeter in series with the conductor of No. I, and, when thrown to the right, places it in series with No. III. Similarly, switch B changes the pressure terminals from between I and II to III and II; while switches C and D are short-circuiting switches, one of which is closed previous to removing the current-coil from one phase to the other, and the other one opened after the coil is in position as indicated.

LOCALIZATION AND REMEDY OF TROUBLES.

The promptness and ease with which any accident or difficulty with electrical machinery can be dealt with, will always have much to do with the success of a plant. The following list of troubles, symptoms, and remedies for the various types and sizes of dynamos and motors in common use, has been prepared to facilitate the detection and elimination of such difficulties.

It is evident that the subject is somewhat complicated and difficult to handle in a general way, since so much depends upon the particular conditions in any given case, every one of which must be included in the table in such a way as to distinguish it from all others Nevertheless, it is remarkable how much can be covered by a systematic statement of the matter, and nearly all cases of trouble most likely to occur are covered by the table, so that the detection and remedy of the defect will result from a proper application of the rules given.

It frequently happens that a trifling oversight, such as allowing a wire to slip out of a binding-post, will cause as much annoyance and delay in the use of electrical machinery as the most serious accident. Other troubles, equally simple but not so easily detected, are of frequent occurrence.

The rules are made, as far as possible, self-explanatory; but a statement of the general plan followed and its most important features will facilitate the understanding and use of the table.

USE OF THE TABLE OF TROUBLES.

In the use of this table, the principal object should be to separate clearly the various causes and effects from one another. A careful and thorough examination should first be made; and, as far as possible, one should be perfectly sure of the facts, rather than attempt to guess what they are and jump at conclusions. Of course, general precautions and preventive measures should be taken before any troubles occur, if possible, rather than to wait until a difficulty has arisen. For example, one should see that the machine is not overloaded or running at too high voltage, and should make sure that the oil-cups are not empty. Neglect and carelessness with any machine are usually and deservedly followed by accidents of some sort. It is usually wise to stop the machine when any trouble manifests itself, even though it does not seem to be very serious. It is often practically impossible to shut down; but even then, spare apparatus should be ready. The continued use of defective machinery is a common but very objectionable practice.

The general plan of the table is to divide all troubles that may occur to generators or motors, into ten classes, the headings of which are the ten most important and obvious bad effects produced in these machines, *viz.:*

I. **Sparking at Commutator.**
II. **Heating of Commutator and Brushes.**
III. **Heating of Armature.**
IV. **Heating of Field Magnets.**
V. **Heating of Bearings.**
VI. **Noisy Operation.**
VII. **Speed not right.**
VIII. **Motor stops or fails to start.**
IX. **Dynamo fails to generate.**
X. **Voltage not right.**

Any one of these general effects is evident, even to the casual observer, and still more so to any person making a careful examination; hence nine-tenths of the possible cases can be eliminated immediately.

The next step is to find out which particular one of the eight or ten causes in this class is responsible for the trouble. This requires more careful examination, but nevertheless can be done with comparative ease in most cases. One cause may produce two effects, and, *vice versa*, one effect may be produced by two causes; but the table is arranged to cover this fact as far as possible. In a complicated or difficult case it is well to read through the entire table and note what causes can possibly apply. Generally there will not be more than two or three; and the particular one can be picked out by following the directions, which show how each case may be distinguished from any other.

I. SPARKING AT THE COMMUTATOR.

This is one of the most common of troubles, being often quite serious because it burns and cuts the commutator and brushes, at the same time producing heat that may spread to and injure the armature or bearings. Any machine having a commutator is liable to it, including practically all direct-current and some alternating-current machines. The latter usually have continuous collecting rings not likely to spark; but self-exciting or composite-wound alternators, rotary converters, and some alternating-current motors have supplementary direct-current commutators. A certain amount of sparking occurs normally in most constant-current dynamos for arc lighting, where it is not very objectionable, since the machines are designed to stand it and the current is small.

CAUSE 1. **Armature carrying too much current,** due to (*a*) overload (for example, too many lamps fed by dynamo, or too much mechanical work done by motor; a short circuit, leak, or ground on the line may also have the effect of overloading a dynamo); (*b*) excessive voltage on a constant-potential circuit, or excessive amperes on a constant-current circuit. In the case of a motor, any friction, such as armature striking pole pieces, or a shaft not turning freely, may have the same effect as overload

SYMPTOM. Whole armature becomes overheated, and belt (if any) becomes very tight on tension side, sometimes squeaking because of slipping on pulley. Overload due to friction is detected by stopping the machine, and then turning it slowly by hand. (See V and VI, 2.)

REMEDY. (*a*) Reduce the load; or eliminate the short circuit, leak, or ground on the line; (*b*) decrease size of driving pulley, or (*c*) increase size of driven pulley; (*d*) decrease magnetic strength of field in the case of a dynamo, or increase it in the case of a motor. If excess of current cannot satisfactorily be overcome in any of the above ways, it will be necessary to change the machine or its winding. Overload due to friction is eliminated as described under V and VI, 2.

If the starting or regulating rheostat of a motor has too little resistance, it will cause the motor to start too suddenly and to spark badly at first. The only remedy is more resistance in the box.

CAUSE 2, **Brushes not set at the neutral point.**

SYMPTOM. Sparking varied by shifting the brushes with rocker-arm.

REMEDY. Carefully shift brushes backwards or forwards until sparking is reduced to a minimum. This can be done by simply moving the rocker-arm. If only slightly out of position, heating alone may result, without disarrangement being bad enough to show sparking. If the brushes are not exactly opposite in a bipolar, 90° apart in a four-pole machine, and so on, they should be made so, the proper points of contact being determined by counting the commutator-bars or by careful measurement.

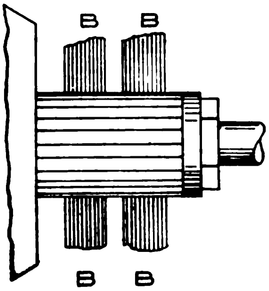


Fig. 57.

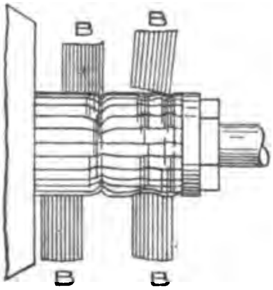


Fig. 58.

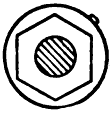


Fig. 59.

The usual position for brushes is opposite the spaces between the pole pieces, but in some machines they must be set in line with centers of pole pieces or at some other point. If the brushes are set exactly wrong, this will cause a dynamo to fail to generate and a motor to fail to start, and will blow the fuse or open the circuit-breaker. (See IX, 6.)

CAUSE 3. **Commutator rough, eccentric, or has one or more "high bars"** projecting beyond the others, or one or more

flat bars, commonly called **flats,** or **projecting mica,** any one of which causes the brushes to vibrate or to be actually thrown out of contact with the commutator (Figs. 58 and 59). Hard mica between the bars, which does not wear as rapidly as the copper, will prevent good contact or throw brushes off.

SYMPTOM. Note whether there is a glaze or polish on the commutator, which shows smooth working; touch revolving commutator with tip of finger nail, and the least roughness is perceptible; or feel brushes to see if there is any jar. If the machine runs at high voltage (over 250), the commutator or brushes should be touched with a stick or quill to avoid danger of shock. In the case of an eccentric commutator, careful examination shows a rise and fall of the brush when the commutator turns slowly, or a chattering of brush when it is running fast. Sometimes, by sighting in line with brush contact, one can see daylight between commutator and brush, owing to brush jumping up and down.

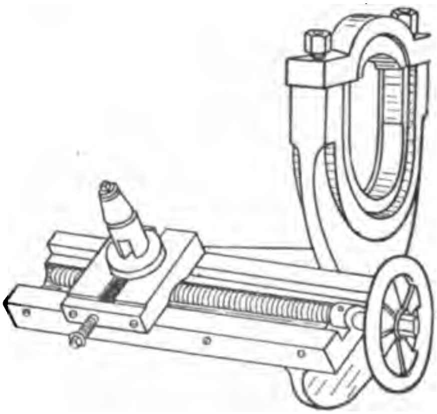


Fig. 60.

REMEDY. Smooth the commutator with a fine file or fine sandpaper, which should be applied on a block of wood that exactly fits the commutator (being careful to remove any sand remaining afterward; and *never use emery*). If commutator is very rough or eccentric, the armature should be taken out and put in a lathe, and the commutator turned off. Large machines often have a slide-rest attachment (Fig. 60), so that the commutator can be turned off without removing the armature. This is clasped on the pillow-block after removing the rocker-arm.

For turning off a commutator, a diamond-pointed tool should be used, this being better than either a round or square end. It should have a very sharp and smooth edge; and only a fine cut should be taken off each time in order to avoid catching in or tearing the copper, which is very tough. The surface is then finished by applying a "dead smooth" file while the commutator revolves rapidly in the lathe. Any particles of copper should then be carefully removed from between the bars.

To have the commutator wear smooth and work well, it is desirable to have the armature shaft move freely back and forth about an eighth of an inch in the bearings while it is running. A commutator should have a glaze of a brown or bronze color. A very bright or scraped appearance does not indicate the best condition. Sometimes a very little vaseline or a drop of oil may be applied to a commutator that is rough. Too much oil is very bad, and causes the following trouble:

CAUSE 4. **Brushes make poor contact with commutator.**

SYMPTOM. Close examination shows that brushes touch only at one corner, or only in front or behind, or there is dirt on surface of contact. Sometimes, owing to the presence of too much oil or from other cause, the brushes and commutator become very dirty, and covered with smut. They should then be carefully cleaned by wiping with oily rag or benzine, or by other means.

Occasionally a "glass-hard" carbon brush is met with. It is incapable of wearing to a good seat or contact, and will touch at only one or two points. Some carbon brushes are of abnormally high resistance, so that they do not make good contact. In such cases new brushes should be substituted.

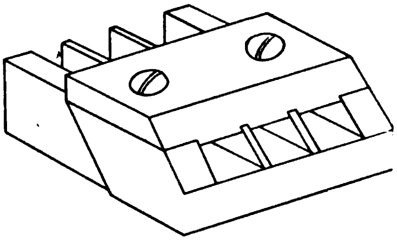


Fig. 61.

REMEDY. Carefully fit, adjust, or clean brushes until they rest evenly on commutator, with considerable surface of contact and with sure but not too heavy pressure. Copper brushes require a regular brush jig (Fig. 61). Carbon brushes can be fitted perfectly by drawing a strip of sandpaper back and forth between them and the commutator while they are pressing down. A band of sandpaper may be pasted or tied around the commutator, and the armature then slowly revolved by hand or by power while the brushes are pressed upon it.

It sometimes happens that the brushes make poor contact because the brush-holders do not work freely.

CAUSE 5. **Short-circuited or reversed coil or coils in armature.**

SYMPTOM. A motor will draw excessive current, even when running free without load. A dynamo will require considerable power, even without any load. For reversed coil, see III, 5.

The short-circuited coil is heated much more than the others, and is liable to be burnt out entirely; therefore the machine should be stopped immediately. If necessary to run machine in order to locate the trouble, one or two minutes is long enough; but this may be repeated until the short-circuited coil is found by feeling the armature all over.

An iron screw-driver or other tool held between the field magnets near the revolving armature, vibrates very perceptibly as the short-circuited coil passes. Almost any armature, particularly one with teeth, will cause a slight but rapid vibration of a piece of iron held near it; but a short circuit produces a much stronger effect only *once* per revolution. Care should be taken not to let the piece of iron be drawn in and jam the armature.

The current pulsates and torque is unequal at different parts of a revolution, these being particularly noticeable when several coils are short-circuited or reversed and the armature is slowly turned. If a large portion of the armature is short-circuited, the heating is distributed and is harder to locate. In this case a motor runs very slowly, giving little power but having full field magnetism. A short-circuited coil can also be detected by the drop-of-potential method. For dynamos, see IX, 3.

REMEDY. A short circuit is often caused by a piece of solder or other metal getting between the commutator-bars or their connections with the armature; and sometimes the insulation between or at the ends of these bars is bridged over by a particle of metal. In any such case the trouble is easily found and corrected. If, however, the short circuit is in the coil itself, the only effective remedy is to rewind the coil.

One or more "grounds" in the armature may produce effects similar to those arising from a short circuit. (See Cause 7.)

CAUSE 6. **Broken circuit in armature.**

SYMPTOM. Commutator flashes violently while running, and commutator-bar nearest the break is badly cut and burnt; but in this case no particular armature coil will be heated as in the last case; and the flashing will be very much worse, even when turning slowly. This trouble, which might be confounded with a bad case of "high bar" in commutator (Cause 3), is distinguished therefrom by slowly turning the armature, when violent flashing will continue if circuit is broken; but not with "high bar" unless it is very bad, in which case it is easily felt or seen. A very bad contact has almost the same effect as a break in the circuit.

Remedy. A break or bad contact can be located by the "drop" method (page 63) or by a continuity test (page 68). The trouble is often found where the armature wires connect with the commutator, and not in the coil itself, and the break may be repaired or the loose wire properly fastened. If the trouble is due to a broken commutator connection, and cannot be fixed, the disconnected bar may be temporarily connected to the next by solder, or the brushes may be "staggered," that is, one put a little forward and the other back so as to bridge over the break (Fig. 62). It may be impracticable to "stagger" radial and some other arrangements of brushes, but usually a brush is thick enough to make contact with more than one commutator bar. If the break is in the coil itself, rewinding is generally the only cure. But this may be remedied temporarily by connecting together by wire or solder the two commutator-bars or coil-terminals between which the break exists. It is only in an emergency that armature coils should be cut out or commutator bars connected together, or other makeshifts resorted to; but it sometimes avoids a very undesirable stoppage. A very rough but quick and simple way to connect two commutator bars, is to hammer or otherwise force the coppers together across the mica insulation at the end of the commutator. This should be avoided if possible; but if it has to be done in an emergency, the crushed material can afterwards be picked out and the injury smoothed over. In carrying out any of these methods, great care should be taken not to short-circuit any other armature coil, which would cause sparking (Cause 5).

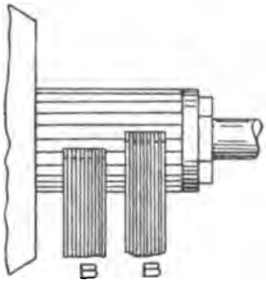


Fig. 62.

CAUSE 7. **Ground in Armature.**

SYMPTOM. Two "grounds" (accidental connections between the conductors on the armature and its iron core or the shaft or spider) would have practically the same effect as a short circuit (Cause 5), and would be treated in the same way. A single ground would have little or no effect, provided the circuit is not intentionally or accidentally grounded at some other point. On an electric-railway ("trolley") or other circuit employing the earth as a return conductor, one or more grounds in the armature would allow the current to pass directly through them, and would cause the motor to spark and have a variable torque at different parts of a revolution.

REMEDY. A ground can be detected by testing with a magneto bell (page 67). It can also be located by the drop-of-potential method (page 63). Another way to locate it is to wrap a wire around the commutator so as to make connection with all of the bars, and then connect a source of current to this wire and to the armature core (by pressing a wire upon the latter). The current will then flow from the armature conductors through the ground connection to the core, and the magnetic effect of the armature winding will be localized at the point where the ground is. This point is then found by the indications of a compass needle when slowly moved around the surface of the armature. The current may be obtained from a storage battery or from the circuit, but should be regulated by lamps or other resistance so as not to exceed the normal armature current. Sometimes the ground may be in a place where it can be corrected without much trouble, but usually the particular coil and often others must be rewound. A ground will be produced if the insulation is punctured by a spark of static electricity, which may be generated by the friction of the belt. If the frame of the machine is connected to the ground, the static charge will pass off to the ground; but such grounding is often inadvisable, and in such cases the frame may be connected to the ground through a Geissler tube, a wet thread, a heavy pencil-mark on a piece of unglazed porcelain, or other very high resistance which will carry off a static charge of very high potential and almost infinitesimal quantity, but will not permit the passage of any considerable current that might cause trouble.

CAUSE 8. **Weak Field Magnetism.**

SYMPTOM. Pole pieces not strongly magnetic when tested with a piece of iron. Point of least sparking is shifted considerably from normal position, owing to relatively strong distorting effect of armature magnetism. Speed of a shunt motor is usually high unless magnetism is very weak or *nil*, in which case a motor may run slow, stop, or even run backwards.* A generator fails to generate the full E.M.F. or current.

The particular cause of trouble may be found as follows: A broken circuit in the field of a motor is found by purposely opening the field circuit at some point, taking care first to disconnect armature (by putting wood under the brushes, for example), and to use only one hand, to avoid shock. If there is no spark when circuit is thus opened, there must be a broken circuit somewhere. A short circuit in the field coils is found by measuring their resistance roughly to see if it is very much less than it should be. Usually a short circuit is confined to one magnet, and will therefore weaken that one more than the others; and a piece of iron held half-way between the pole pieces will be attracted to one more than to the other. The short circuit may be found by the drop-of-potential method, by testing from the joint between the field coils to each outside terminal. "Grounding" is practically identical with short-circuiting, but one ground will not produce this effect until another occurs. A double ground, through which the current finds a complete path, is equivalent to a short circuit. In the ordinary "trolley" electric-railway system, a ground return is used, and the neutral conductor of three-wire systems is often grounded. In such cases one ground may be sufficient to cut out one or more field coils.

If one field coil is reversed and opposed to the others, it will weaken the field magnetism and cause bad sparking. This may be detected by examining the field coils to see if they are all connected in the right way, or by testing with a compass needle. (See IX, 4.) The series-coil of a compound-wound dynamo or motor is ofted connected wrongly, and will have the wrong effect, that is, will reduce the voltage of the former or raise the speed of the latter with increase of load.

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* **NOTE. If the motor is not loaded, it will race.**

REMEDY. A broken or short circuit or a ground is easily repaired if external or accessible. If it is internal, the only remedy is to replace or rewind the faulty coil. A shunt motor will spark badly in starting if the armature is connected before the field. This can be remedied by adjusting the contacts and switch-arm. If the voltage is too low on the circuit, it may cause sparking in a shunt dynamo or motor; and if the voltage cannot be raised, the resistance of the field circuit should be reduced by unwinding a few layers of wire or by substituting other coils (See VII, VIII, IX, and X.)

CAUSE 9. **Vibration of Machine.**

SYMPTOM. Considerable vibration is felt when the hand is placed upon the machine, and sparking decreases if the vibration is reduced.

REMEDY. The vibration is usually due to an imperfectly balanced armature or pulley (see VI, 1), to a bad belt (see VI, 6), or to unsteady foundations; and the remedies described for these troubles should be applied.

Any considerable vibration is likely to produce sparking, of which it is a common cause. This sparking can be reduced by increasing the pressure of the brushes on the commutator, but the vibration itself should be overcome.

CAUSE 10. **Chatter of Brushes.**

The commutator sometimes becomes sticky when carbon brushes are used, causing friction, which throws the brushes into rapid vibration as the commutator revolves, similar to the action of a violin bow.

SYMPTOM. Slight tingling or jarring is felt in brushes.

REMEDY. Clean commutator, and oil slightly.

CAUSE 11. **Flying break in armature conductor.**

SYMPTOM. No break found by test with armature standing still, but break shown by flashing at brushes. when running, being usually due to centrifugal force.

REMEDY. Tighten connections to commutator, or repair broken wire, etc.

EXCESSIVE HEATING IN GENERATOR OR MOTOR.

General Instructions. The degree of heat that is injurious or objectionable in a generator or motor is easily determined by feeling the various parts. If the heat is bearable to the hand, it is entirely harmless; but if unbearable, the safe limit of temperature has been approached or passed, and the heat should be reduced in some of the ways that are indicated below. In testing with the hand, allowance should be made for the fact that bare metal feels much hotter than cotton at the same temperature. The back of the hand is more sensitive than the palm for this test. If the heat has become so great as to produce an odor or smoke, the safe limit has been far exceeded, and the current should be shut off immediately and the machine stopped, as this indicates a serious trouble, such as a short-circuited coil or tight bearing. The machine should not again be started until the cause of the trouble has been found and positively overcome. Of course, neither water nor ice should ever be used to cool electrical machinery, except possibly the bearings of large machines at points where they can be applied without danger of wetting the other parts.

Feeling for heat will serve as a rough test to detect excessive temperatures or in emergencies; but, of course, the sensitiveness of the hand varies, and it makes a great difference whether the surface is a good or bad conductor of heat. The proper and reliable methods for determining rise in temperature are given on page 59, Part I.

It is very important, in all cases of heating, to locate the source of heat in the exact part in which it is produced. It is a common mistake to suppose that any part of a machine that is found to be hot is the seat of the trouble. A hot bearing may cause the armature or commutator to heat, or *vice versa*. In every case all parts of the machine should be tried to find which is the hottest, since heat generated in one part is rapidly diffused throughout the entire machine. It is better to make observations for heating by starting with the whole machine cool, which is done by letting it stand for several hours.

II. HEATING OF COMMUTATOR AND BRUSHES.

Cause 1. **Heat spread from another part of machine.**

Symptom. Start with the machine cool, and run for a short time, so that heat will not have time to spread. The real seat of trouble is the part that heats first.

Remedy. (See Heating of Armature, Fields, and Bearings.)

CAUSE 2. **Sparking.** Any of the causes of sparking will cause heating, which may be slight or serious.

SYMPTOM and REMEDY. See "Sparking."

CAUSE 3. **Tendency to spark, or slight sparking hardly visible.**

Sometimes before sparking appears, serious heating is produced by the causes of sparking, such as the short-circuiting of the coils as their commutator-bars pass under the brushes.

SYMPTOM. Reduced by applying the principal remedies for sparking, such as slightly shifting rocker-arm. Fine sparks may be found by sighting in exact line with the surface of contact between the commutator and brushes.

REMEDY. (See "Sparking.") Apply the remedies with extra care. This incipient sparking may be due to excessive inductance in the armature coils, which can be corrected only by reconstruction; or it may be due to insufficient field strength, and this can be cured by increasing the ampere-turns of field winding.

CAUSE 4. **Overheated commutator will decompose carbon brush.**

The effect is to cover commutator with a black film which offers resistance and aggravates the heat.

SYMPTOM. Commutator covered with dark coating; commutator, brushes and holders show marks of abnormal heat.

REMEDY. Commutator and brushes should be carefully cleaned, and the latter adjusted to make good contact at the proper points.

CAUSE 5. **Bad connections in brush-holder, cable, etc.**

SYMPTOM. Holder, cable, etc., feel hottest; unusual resistance found in these parts by "drop method."

REMEDY. Improve the connections.

CAUSE 6. **Arcing or short circuit in commutator.**

This may occur across mica or insulation between bars or nuts.

SYMPTOM. Burnt spot between parts; spark appears in the insulation when current is put on.

REMEDY. Pick out the charred particles; take commutator apart and repair; or put on new commutator.

CAUSE 7. **Carbon brushes heated by the current.**

Carbon brushes require less attention than copper, because they do not cut the commutator, and their resistance usually reduces sparking, but it may also cause them to heat.

Symptom. **Brushes hotter than other parts.**

Remedy. **Use carbon of higher conductivity. Let the brush-holder grip brush closer to commutator, so as to reduce the length of brush through which the current must pass.** Reinforce the brush with copper gauze or sheet copper. Use larger brushes or a greater number.

III. HEATING OF ARMATURE.

Cause 1. **Excessive current in armature coils.**

Symptom and Remedy the same as in case of "Sparking," Cause 1.

Cause 2. **Short-circuited armature coils.**

Symptom and Remedy the same as in case of "Sparking;" Cause 5. See also Cause 7.

Cause 3. **Moisture in armature coils.**

Symptom. Armature requires considerable power to run free. Armature steams when hot, or feels moist. This is really a special case of Cause 2, as moisture has the effect of short-circuiting the coils through the insulation. Measure insulation resistance of armature ; this should test at least one megohm if armature is in good condition, but would be much lowered by moisture. (See "Insulation Tests.")

Remedy. The armature should be baked for 5 to 10 hours in an oven or other place sufficiently warm to drive out the moisture, but not hot enough to run any risk of burning or even slightly charring the insulation. A neat way to do this is to pass through the armature a current regulated to be about three quarters of the rated armature current, the armature being held still or turned over occasionally.

Cause 4. **Foucault currents in armature core.**

Symptom. Iron of armature core hotter than coils after a short run, and considerable power required to run armature when

Note. Any excess of current taken by an armature when running *free*, whatever the cause, must be converted into heat by some defect in the motor; hence the "free current" is the simplest and most complete test of the efficiency and perfect condition of the machine.

field is magnetized and there is no load on armature. This can be distinguished from Cause 2 by absence of sparking and absence of excessive heat in a particular coil or coils after a short run. (See "Stray Power Tests.")

REMEDY. Armature core should be laminated more perfectly, which is a matter of first construction.

CAUSE 5. **One or more reversed coils on one side of armature.** This will cause a local current to circulate around armature.

SYMPTOM. Excessive current when running free, but no particular coil heated more than others. If a moderate current is applied to each coil in succession by touching wires carrying current to each two adjacent commutator-bars, a compass needle held over the coils will behave differently when the reversed coil is reached. In a motor the half of armature containing the reversed coils is heated more than the other.

REMEDY. Reconnect the coil to agree with the others.

CAUSE 6. **Heat conveyed from other parts.**

SYMPTOM. Other parts hotter than armature. Start with machine cool, and see if other parts heat first.

REMEDY. See Heating of Bearings, Field and Commutator.

CAUSE 7. **Flying cross in armature conductor.**

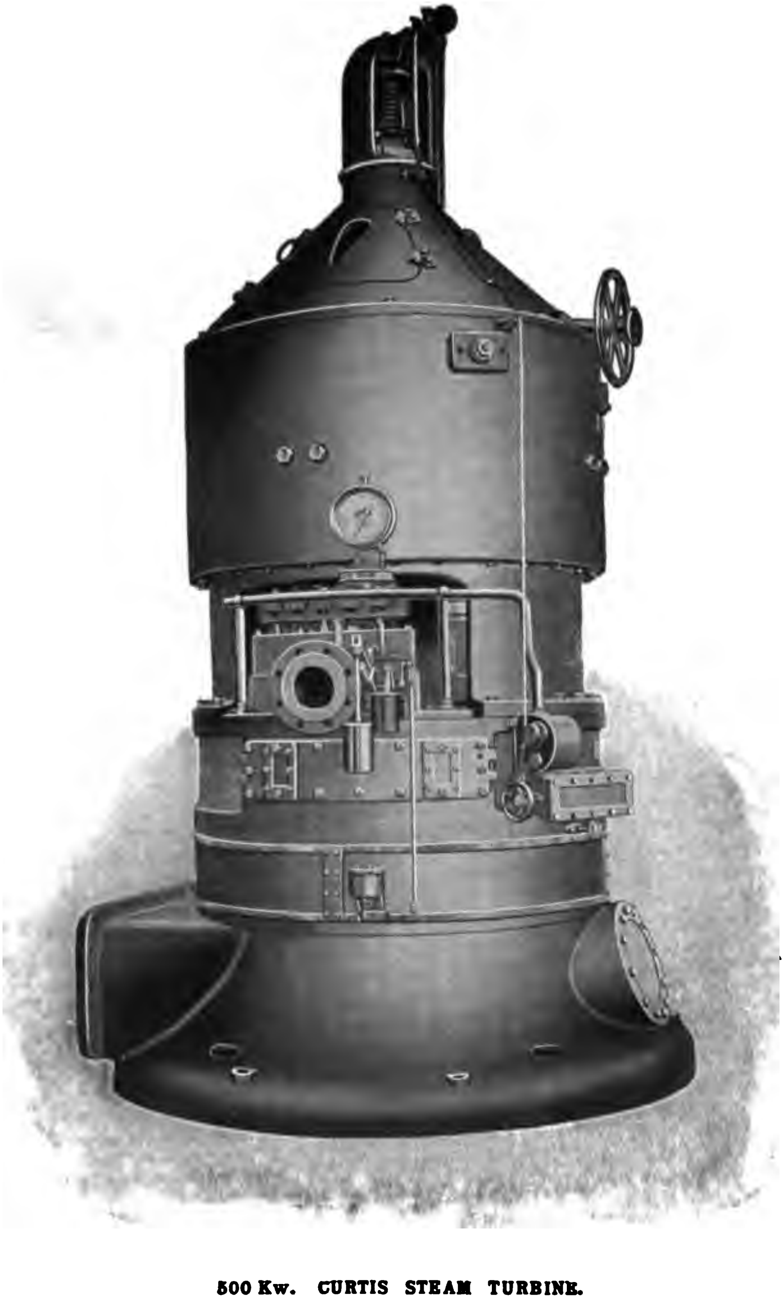
SYMPTOM and REMEDY similar to the case of sparking (Cause 11), except that reference here is to the insulation of the conductors.

IV. HEATING OF FIELD MAGNETS.

CAUSE 1. **Excessive current in field circuit.**

SYMPTOM. Field coils too hot to keep the hand on. Their temperature more than 50°C above that of room by resistance test or by thermometer.

REMEDY. In the case of a shunt-wound machine, decrease the voltage at terminals of field coils; or increase the resistance in field circuit by winding on more wire or putting resistance in series. In the case of a series-wound machine, shunt a portion of, or otherwise decrease, the current passing through field; or take a layer or more of wire off the field coils; or rewind with coarser wire. This trouble might be due to a short circuit in field coils in the case of a shunt-wound dynamo or motor, and would be indicated by the



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pole piece with the short-circuited coil being weaker than the others. This coil is cooler than the others; in fact, if completely short-circuited, it is not heated at all. This condition can be remedied only by rewinding the short-circuited coil. Measure resistance of the field coils to see if they are nearly equal. (See "drop method.") If the difference is considerable (say, more than 5 or 10 per cent), it is almost a sure sign that one coil is short-circuited or double-grounded.

CAUSE 2. **Foucault currents in pole pieces or field cores.**

SYMPTOM. The pole pieces hotter than the coils after a short run. When making the comparison, it is necessary to keep the hand on the coils some time before the full effect is reached, because the coils are insulated and the pole pieces are bare metal, and even then the coils will not feel so hot, although their actual temperature may be higher if measured by a thermometer.

REMEDY. This trouble is due to faulty design of toothed-armature machines, which can be corrected only by rebuilding, or is caused by fluctuations in the current. The latter can be detected, if the variations are not too rapid, by putting an ammeter in circuit; or rapid variations may be felt by holding a piece of iron near the pole pieces, and noting whether it vibrates. In the case of an alternating current it is necessary to use laminated fields to avoid great heating.

CAUSE 3. **Moisture in field coils.**

SYMPTOM. The field circuit tests lower in resistance than normal in that type of machine; and in the case of shunt-wound machines, the field takes more than the ordinary current. Field coils steam when hot, or feel moist to hand. The insulation resistance also tests low.

REMEDY. The same as for moisture in armature (III, 3).

V. HEATING OF BEARINGS.

The cause should be found and removed promptly, but heating of the bearings can be reduced temporarily by applying cold water or ice to them. This is allowable only when absolutely necessary to keep running; and great care should be taken not to allow any water to get upon the commutator, armature, or field-coils, as it might short-circuit or ground them. If the bearing is very hot, the shaft should be kept revolving slowly, as it might "freeze," or stick fast, if stopped entirely.

CAUSE 1. **Lack of oil.**

SYMPTOM. Oil-cup reservoir empty. Oil passages clogged. Self-oiling rings stick fast. Shaft and bearing look dry. The shaft does not turn freely.

REMEDY. Supply oil, and make sure that oil passages as well as feeding or self-oiling devices work freely, and that the oil cannot leak out. This last fault sometimes causes oil to fail sooner than attendant expects. A good quality of oil should always be used, as poor oil might be as bad as no oil.

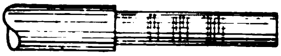


Fig. 63.

CAUSE 2. **Grit or other foreign matter in bearings.**

SYMPTOM. Best detected by removing shaft or bearing and examining both. Any grit can of course be felt easily, and will also cut the shaft.

REMEDY. Remove shaft or bearing, clean both very carefully, and see that no grit can get in. Place machine in dustless place or box it in. The oil should be perfectly clean; if not, it should be filtered. If it is not possible to stop the machine or to remove the shaft, the dirt may be washed out with kerosene or water; but these should not be allowed to get on the commutator, armature, or field coils.

CAUSE 3. **Shaft rough or cut.** (Fig. 63.)

SYMPTOM. Shaft will show grooves or roughness, and will probably revolve stiffly.

REMEDY. Turn shaft in lathe; or smooth with fine file; and see that bearing is smooth and fits shaft.

CAUSE 4. **Shaft and bearing fit too tight.**

SYMPTOM. Shaft hard to revolve by hand.

REMEDY. Turn or file down shaft in lathe, or scrape or ream out bearings.

CAUSE 5. **Shaft "sprung" or bent.**

SYMPTOM. Shaft hard to revolve, and usually sticks much more in one part of revolution than in another.

REMEDY. It is very difficult to straighten a bent shaft. It might be bent back or turned true, but probably a new shaft will be necessary.

CAUSE 6. **Bearings out of line.**

SYMPTOM. Shaft hard to revolve, but is much relieved by slightly loosening the screws that hold bearings in place, when machine is not running and when belt, if any, is taken off.

REMEDY. Loosen the bearings by partly unscrewing bolts or screws holding them in place, and find their easy and true position, which may require one of them to be moved either sideways or up or down; then file the screw-holes of that bearing, or raise or lower it, as may be necessary, to make it occupy the right position when the screws are tightened. The armature, however, must be kept in the center of the space between the pole pieces, so that the clearance is uniform all around. (See Cause 9.)

CAUSE 7. **Thrust or pressure of pulley, collar, or shoulder on shaft against one or both of the bearings.**

SYMPTOM. Move shaft back and forth with a stick applied to the end while revolving, and note if the collar or shoulder tends to be pushed or drawn against either bearing. It is usually desirable that a shaft should move freely back and forth about an eighth of an inch, to make commutator and bearings wear smoothly.

REMEDY. Line up the belt; shift collar or pulley; turn off shoulder on shaft, or file off bearing, until the shoulder does not touch when running, or until pressure is relieved.

CAUSE 8. **Too great a load or strain on the belt.**

SYMPTOM. Great tension on belt. In this case the pulley bearing will probably be very much hotter than the other, and also worn elliptical, as indicated in Fig. 64, in which case the shaft can be shaken in the bearing in the direction of the belt pull, when the belt is off, provided the machine has been running long enough to wear the bearings.

REMEDY. Reduce load or belt tension, or use larger pulleys and lighter belt, so as to relieve side strain on shaft. (See "Belting.")

CAUSE 9. **Armature too near one pole piece, producing much greater magnetic attraction on nearer side.**

SYMPTOM. Examine the clearance of armature to see if it is uniform on all sides. Charge and discharge the field magnet, the armature being disconnected (by putting wood under the brushes);

and note whether armature seems to be drawn to one side and turns very much less easily when field is magnetized.

REMEDY. This fault is due either to a defect in the original construction, or to wear in the bearings, either of which is difficult to correct; but in cases of necessity the armature can be centered exactly in the field by moving the bearings, which may be done by carefully filing the holes through which the screws pass that hold the bearings in place; or the pole piece may be filed away where it is too near the armature.

Trouble from this cause is greater in multipolar than in bipolar machines, and always tends to become aggravated, because the more the side pull the more the bearings wear in that direction. If, on the other hand, the armature is in the center of the space formed by the pole pieces, the magnetic pull is practically balanced in all directions.

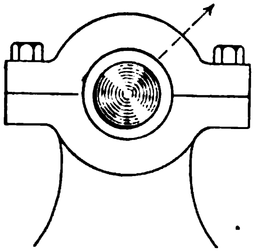


Fig. 64.

It is risky to file bolt-holes or make any such change in a machine; and this should never be attempted before consulting an experienced machinist. Very often the trouble is due to the parts being out of place merely because they have not been put together right or because there is dirt between them. If the bearing is worn, it may be rebabbitted or renewed.

CAUSE 10. **Bearing heated by hot pulley, commutator, or armature.**

SYMPTOM. Pulley, armature, or commutator hotter than bearing. The slipping of the belt on the pulley, sparking at the commutator, or heating of the armature may heat one or both bearings of the machine, in which case an examination will show that these parts are hotter than the bearing, and the real source of the trouble.

REMEDY. A slipping belt, sparking commutator, or hot armature can be cured as described under these headings, and then the bearing will probably cease to heat.

VI. NOISY OPERATION.

CAUSE 1. **Vibration due to armature or pulley being out of balance.**

SYMPTOM. Strong vibration felt when the hand is placed upon the machine while it is running. Vibration changes greatly if speed is changed, and sometimes almost disappears at certain speeds.

REMEDY. Armature or pulley must be perfectly balanced by securely attaching lead or other weight on the light side, or by drilling or filing away some of the metal on the heavy side. The easiest method of finding in which direction the armature is out of balance is to take it out, and to rest the shaft on two parallel and horizontal A-shaped metallic tracks sufficiently far apart to allow the armature to go between them (Fig. 65). If the armature is then slowly rolled back and forth, the heavy side will tend to turn downward. The armature and pulley should always be balanced separately. An excess of weight on one side of the pulley and an equal excess of weight on the opposite side of the armature will not produce a balance while running, though it does when standing still; on the contrary, it will give the shaft a strong tendency to "wobble." A perfect balance is obtained only when the weights are directly opposite, *i.e.*, in the same line perpendicular to the shaft.

CAUSE 2. **Armature strikes or rubs against pole pieces.**

SYMPTOM. Easily detected by placing the ear near the pole pieces; or by examining armature to see if its surface is abraded at any point; or by examining each part of the space between armature and field as armature is slowly revolved, to see if any portion of it touches or is so close as to be likely to touch when the machine is running. In small machines, the armature may be turned by hand, noting whether it sticks at any point.

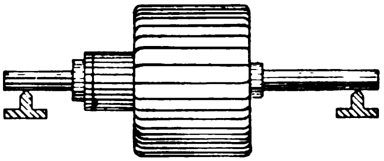


Fig. 65.

REMEDY. Bind down any wire or other part of the armature that may project abnormally; or file out the pole pieces where the armature strikes; or center the armature so that there is a uniform clearance between it and the pole pieces at all points.

CAUSE 3. **Shaft collar or shoulder, hub or edge of pulley, or belt, strikes or scrapes against bearings.**

Symptom. Rattling noise, which stops when the shaft or pulley is pushed lengthwise away from one or the other of the bearings. (See "Heating of Bearings," Cause 7.)

Remedy. Shift the collar or pulley, turn off the shoulder on the shaft, file or turn off the bearing, move the pulley on the shaft, or straighten the belt, until there is no more striking, and the noise ceases.

Cause 4. **Rattling due to looseness of screws or other parts.**

Symptom. Close examination of the bearings, shaft, pulley, screws, nuts, binding-posts, etc., or touching the machine while running, or shaking its parts while standing still, shows that some parts are loose.

Remedy. Tighten up the loose parts, and be careful to keep them all properly set up. It is easy to guard against the occurrence of this trouble, which is very common, by simply examining the various screws and other parts each day before the machine is started. Electrical machinery being usually high-speed, the parts are particularly liable to shake loose. A worn or poorly fitted bearing might allow the shaft to rattle and make a noise, in which case the bearing should be refitted or renewed.

Cause 5. **Singing or hissing of brushes.** This is usually occasioned by rough or sticky commutator (see "Sparking," Causes 3 and 10), or by brushes not being smooth, or by the layers of a copper brush not being held together and in place. With carbon brushes, hissing will be caused by the use of carbon that is gritty or too hard. Vertical carbon brushes, or brushes inclined against the direction of rotation, are liable to squeak or sing. Occasionally, a new machine will make noise that is reduced after the machine has been run for some time.

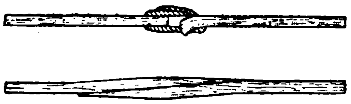


Fig. 66.

Symptom. Sound of high pitch, and easily located by placing the ear near the commutator while it is running, and by lifting off the brushes one at a time, provided there are two or more in each set, so that the circuit is not opened. If there is no current there is no objection to raising the brushes.

Remedy. Apply a *very little* oil or vaseline to the commutator with the finger or a rag. Adjust the brushes or smooth the commutator by turning or filing, or by using fine sandpaper, being careful to clean thoroughly afterwards. Carbon brushes are liable to squeak in starting up or at low speed. This decreases at full speed, and can generally be stopped by moistening the brushes with oil, care being taken not to have any drops or excess of oil. Shortening or lengthening the brushes sometimes stops the noise. Running the machine without load for some time usually reduces this trouble.

Cause 6. **Flapping or pounding of belt joint or lacing against pulley.** (Fig. 66.)

Symptom. Sound repeated once for each complete revolution of the belt, which is much less frequent than any other generator or motor sound, and can easily be detected or counted.

Remedy. Endless belt or smoother joint. (See "Belting.")

Cause 7. **Slipping of belt on pulley due to overload.**

Symptom. Intermittent squeaking noise.

Remedy. Tighten the belt or reduce the load. A wider belt or larger pulley may be required. Powdered rosin may be put on the belt to increase its adhesion ; but it is a makeshift, injurious to the belt, to be adopted only if necessary. (See "Belting.")

Cause 8. **Humming of armature-core teeth as they pass pole-pieces.**

Symptom. Pure humming sound less metallic than Cause 5.

Remedy. Slope or chamfer the ends of the pole pieces so that each armature tooth does not pass the edge of the pole piece all at once. Decrease the magnetization of the fields. Increase the air-gap or reduce the distance between the teeth. But these are nearly all matters of first construction and are made right by good manufacturers.

Cause 9. **Humming due to alternating or pulsating current.**

Symptom This gives a sound similar to that in the preceding case. The two can be distinguished, if necessary, by determining whether the note given out corresponds to the number of alternations, or to the number of armature teeth passing per second.

Usually the latter is considerably greater than the former.

Remedy. This trouble is confined to alternating apparatus, and its effects can be reduced by proper design and by mounting the machine so as to deaden the sound as far as possible.

It often happens that a generator or motor seems to make a noise, which in reality is caused by the engine or other machine with which it is connected. Careful listening with the ear close to the different parts will show exactly where the noise originates. A very sensitive method of locating a noise or vibration is to hold a short stick by one end between the teeth, and press the other end squarely against the several parts, to ascertain which particular one gives the greatest vibration.

VII. SPEED TOO HIGH OR TOO LOW.

This is generally a serious matter in either generator or motor, and it is always desirable and often imperative to shut down immediately, and make a careful investigation.

SPEED TOO LOW.

Cause 1. **Overload.** (See "Sparking," Cause 1.)

Symptom. Armature runs more slowly than usual. Bad sparking at commutator. Ammeter indicates excessive current. Armature heats. Belt very tight on tension side.

Remedy. Reduce the load on machine, decrease the diameter of driving pulley, or increase the diameter of driven pulley. If necessary to relieve strain of overload, temporarily decrease the voltage on either a generator or a motor.

Cause 2. **Short circuit or ground in armature.**

Symptom and Remedy the same as in case of "Heating of Armature, Cause 2 and Cause 6.

Cause 3. **Armature strikes pole pieces.**

Symptom and Remedy the same as in case of "Noise," Cause 2.

Cause 4. **Shaft does not revolve freely in the bearings.**

Symptom and Remedy the same as for "Heating of Bearings," all cases.

SPEED TOO HIGH OR TOO LOW.

Cause 5. **Field magnetism weak.**

This has the effect, on a constant-voltage circuit, of making a motor run too fast if lightly loaded, or too slow if heavily loaded, or even run backwards if the field magnet is not excited at all, as, for example, when the field circuit is broken. It makes a generator fail to "build up" or excite its field, or give the proper voltage in any case.

Symptom and Remedy the same as in case of "Sparking," Cause 8. (See the following Cause; also "Dynamo Fails to Generate ')

Cause 6. **Too high or too low voltage on the circuit.**

Symptom. This would cause a motor to run too fast or too slow, respectively. It can be shown by measuring the voltage of the circuit.

Remedy. The central station or generating plant should be notified that voltage is not right.

SPEED TOO HIGH.

Cause 7. **Motor too lightly loaded.**

Symptom. A series-wound motor on a constant-potential circuit runs too fast, and may speed up to the bursting point if the load is very much reduced or removed entirely (by the breaking of the belt, for example).

Remedy. Care should be exercised in using a series motor on a constant-potential circuit, except where the load is a fan, pump, or other machine that is *positively* connected or geared to the motor so that there is no danger of its being taken off. A shunt motor should be used if the load is likely to be thrown off.

VIII. MOTOR STOPS OR FAILS TO START.

This is an extreme case of the previous class ("Speed Too High or Too Low"), but is separated because it is more definite and permits of quicker diagnosis and treatment. This heading does not, of course, apply to generators, since any trouble in setting these in motion is usually outside of the machine itself.

Cause 1. **Great overload.**

A slight overload causes motor to run slowly, but an extreme overload will, of course, stop it entirely or "stall" it. (See "Sparking," Cause 1.)

Symptom. On a constant-potential circuit the current is excessive, and safety-fuse blows or circuit-breaker opens. In their absence or failure, armature is burnt out.

Remedy. Turn off switch instantly, reduce or take off the load, replace the fuse or circuit-breaker, if necessary, and turn on current again just long enough to see if trouble still exists; if so, take off more load.

CAUSE 2. **Very excessive friction due to shaft, bearings, or other parts being jammed, or armature touching pole pieces.**

SYMPTOM. Similar to previous case, but distinguished from it by the fact that the armature is hard to turn even when load is taken off. Examination shows that the shaft is too large or is bent or rough, that the bearing is too tight, that the armature touches pole pieces, or that there is some other impediment to free rotation. (See "Heating of Bearings" and "Noise.")

REMEDY. Turn current off instantly, ascertain and remove the cause of friction, turn on the current again just long enough to see if trouble still exists; if so, investigate further.

CAUSE 3. **Circuit open.**

This may be due to (*a*) safety-fuse blown or circuit-breaker open; (*b*) wire in motor broken or slipped out of connections; (*c*) brushes not in contact with commutator; (*d*) switch open; (*e*) circuit supplying motor open; (*f*) failure at generating plant.

SYMPTOM. Distinguished from causes 1 and 2 by the fact that if the load is taken off, the motor still refuses to start, and yet armature turns freely.

On a constant-potential circuit the field circuit alone of a shunt motor may be open, in which case the pole pieces are not strongly magnetic when tested with a piece of iron, and there is a dangerously heavy current in the armature; if the armature circuit is at fault, there is no spark when the brushes are lifted; and if both are without current, there is no spark when switch is opened. One should be very careful if there is no field magnetism or even if it is weak, as a motor is liable to be burnt out if the current is then thrown upon the armature.

REMEDY. Turn current off instantly. Examine safety-fuse circuit-breaker, wires, brushes, switch, and circuit generally, for break or fault. If none can be found, turn on switch again for a moment, as the trouble may have been due to a temporary stoppage of the current at the station or on the line. If motor still seems dead, test separately armature, field coils, and other parts of circuit for continuity with a magneto or a cell of battery and an electric bell, to see if there is any break in the circuit. (See "Instructions for Testing.")

One of the simplest ways to find whether the circuit has current on it and to locate any break, is to test through an incandescent lamp. Two or five lamps in series should be used on 220- and 500-volt circuits, respectively.

CAUSE 4. **Wrong connection or complete short circuit of field, armature, switch, etc.**

SYMPTOM. Distinguished from Causes 1 and 2 in the same way as Cause 3, and differs from Cause 3 in the evidence of strong current in motor.

On a constant-potential circuit, if current is very great, it indicates a short circuit. If the field is at fault, it will not be strongly magnetic.

The possible complications of wrong connections are so great that no exact rules can be given. Carefully examine and make sure of the correctness of all connections (see Diagrams of Connections). This trouble is usually inexcusable, since only a competent person should ever set up a machine or change its connections.

In the 3-wire (220-volt direct-current) system, several peculiar conditions may exist, as follows:

(*a*) The dynamo or dynamos on one side of the system may become reversed, so that both of the outside wires are positive or negative. In that case a motor fed in the usual way from the two outside conductors will get no current, but lamps connected between the neutral wire and either of the outside wires will burn as usual.

(*b*) If one of the outside wires is open by the blowing of a fuse, an accidental break, or other cause, then a motor (220-volt) beyond the break can get some current at 110 volts through any lamps that may be on the same side of the break as itself, and on the same side of the system as the conductor that is open. These lamps will light up when the motor is connected, but the motor will have little or no power unless the number of lamps is large.

(*c*) If the neutral or middle wire is open, a motor connected with the outside wires will run as usual; but lamps on one side of the system will burn more brightly than those on the other side, unless the two sides are perfectly balanced.

(*d*) If one of the outside wires becomes accidentally grounded, a 110-volt dynamo, motor, or other apparatus, also grounded and connected to the other outside wire, will receive 220 volts, which will probably burn it out.

IX. DYNAMO FAILS TO GENERATE.

This trouble is almost always caused by the inability of a dynamo to "excite" or "build up" its field-magnetism sufficiently. The proper starting of a self-exciting dynamo requires a certain amount of residual magnetism, which must be increased to full strength by the current generated in the machine itself. This trouble is not likely to occur in a separately-excited machine; and if it does it is usually due to the exciter failing to generate, and therefore amounts to the same thing.

CAUSE 1. **Residual magnetism too weak or destroyed.**

This may be due to (*a*) vibration or jar; (*b*) proximity of another dynamo; (*c*) earth's magnetism; (*d*) accidental reversed current through fields, not enough to completely reverse magnetism. The complete reversal of the residual magnetism in any dynamo will not prevent its generating, but will only make it build up of opposite polarity. Sometimes reversal of residual magnetism may be very objectionable, as in case of charging storage batteries; but, although the popular supposition is to the contrary, it will not cause the machine to fail to generate.

SYMPTOM. Little or no magnetic attraction when the pole pieces are tested with a piece of iron.

REMEDY. Send a magnetizing current from another machine or battery through the field coils, then start and try the machine; if this fails, apply the current in the opposite direction, since the magnets may have enough polarity to prevent the battery building them up in the direction first tried.

Shift the brushes backward in a generator, or forward in a motor to make armature magnetism assist field. Turn machine around or change its polarity, so that the magnetism which the earth or the adjacent machine tends to induce is in the right direction. Dynamos should be placed with their opposite poles toward each other, and the north pole of a machine should preferably be placed toward the north (which is magnetically the *south* pole of the earth); but the earth's magnetism is hardly strong enough to reverse a dynamo's residual magnetism.

Cause 2. **Reversed connections or reverse direction of rotation.**

Symptom. When running, pole pieces show no attraction for a piece of iron. The application of external current cannot be made to start the machine, as in case of Cause 1, because, whichever way the field may be magnetized, the resulting current generated by armature opposes and destroys the magnetism.

Remedy. (*a*) Reverse either armature connections or field connections, *but not both.* (*b*) Move brushes through 180° for 2-pole, 90° for 4-pole machines, etc. (*c*) Reverse direction of rotation. After each of the above are tried, the field may have to be built up with a battery or other current, since the causes in this case operate to destroy whatever residual magnetism may have been present.

Cause 3. **Short circuit in the machine or external circuit.**

This applies to a shunt-wound machine, and has the effect of preventing the voltage and the field magnetism from building up.

Symptom. Magnetism weak, but still quite perceptible.

Remedy. If the short circuit is in the external circuit, opening the latter will allow the dynamo to build up and generate full voltage. If the short circuit is within the machine, it should be found by careful inspection or testing. In either of these cases, do not connect the external circuit until short circuit is found and eliminated. A slight short curcuit, such as that caused by a defective lamp socket or by copper dust on the brush-holder or commutator, may prevent the magnetism of a shunt machine from building up. (See "Sparking," Causes 5 and 8.) Too many lamps, or other load, might prevent a shunt dynamo from building up its field magnetism, in which case the load should be disconnected in starting.

Cause 4. **Field-coils opposed to each other.**

Symptom. Upon passing a current from another dynamo of a battery the following symptom will exist: If the pole-pieces of a bipolar machine are approached with a compass or other freely suspended magnet, they both attract the same end of the magnet, showing them to be of the same polarity, whereas they should always be of opposite polarity.

For similar reasons the pole-pieces are magnetic when tested separately with a piece of iron, but show less attraction when the same piece of iron is applied to both at once, in which latter case the attraction should be stronger. In multipolar machines these tests should be applied to consecutive pole-pieces.

REMEDY. Reverse the connections of one of the coils in order to make the polarity of the pole-pieces opposite. The pole-pieces should be alternately north and south (when tested by compass).

CAUSE 5. **Open circuit.**

This may be due to (*a*) broken wire or faulty connection in machine; (*b*) brushes not in contact with commutator; (*c*) safety fuse melted or absent; (*d*) switch open; (*e*) external circuit open.

SYMPTOM. If the trouble is merely due to the switch or external circuit being open, the magnetism of a shunt dynamo may be at full strength, and the machine itself may be working perfectly; but if the trouble is in the machine, the field magnetism will probably be very weak.

REMEDY. Make very careful examination for open circuit; if not found, test separately the field-coils, armature, etc., for continuity, with magneto or cell of battery and electric bell. (See "Instructions for Testing;" also " Motor Stops," etc., Cause 3.)

A break, poor contact, or excessive resistance in the field circuit or regulator of a shunt dynamo will also make the magnetism weak and prevent its building up. This may be detected and overcome by cutting out the rheostat for a moment by connecting the two terminals of the field-coils to the two brushes respectively, care being taken not to make a short circuit.

A break or abnormally high resistance anywhere in the circuit of a series-wound dynamo will prevent it from generating, since the field-coil is in the main circuit. This may be detected and overcome by short-circuiting the machine for a moment in order to start up the magnetism.

Either of these two remedies by short-circuiting should be applied very carefully, and not until the pole-pieces have been tested with a piece of iron to make sure that the magnetism is weak.

CAUSE 6. **Brushes not in proper position.**

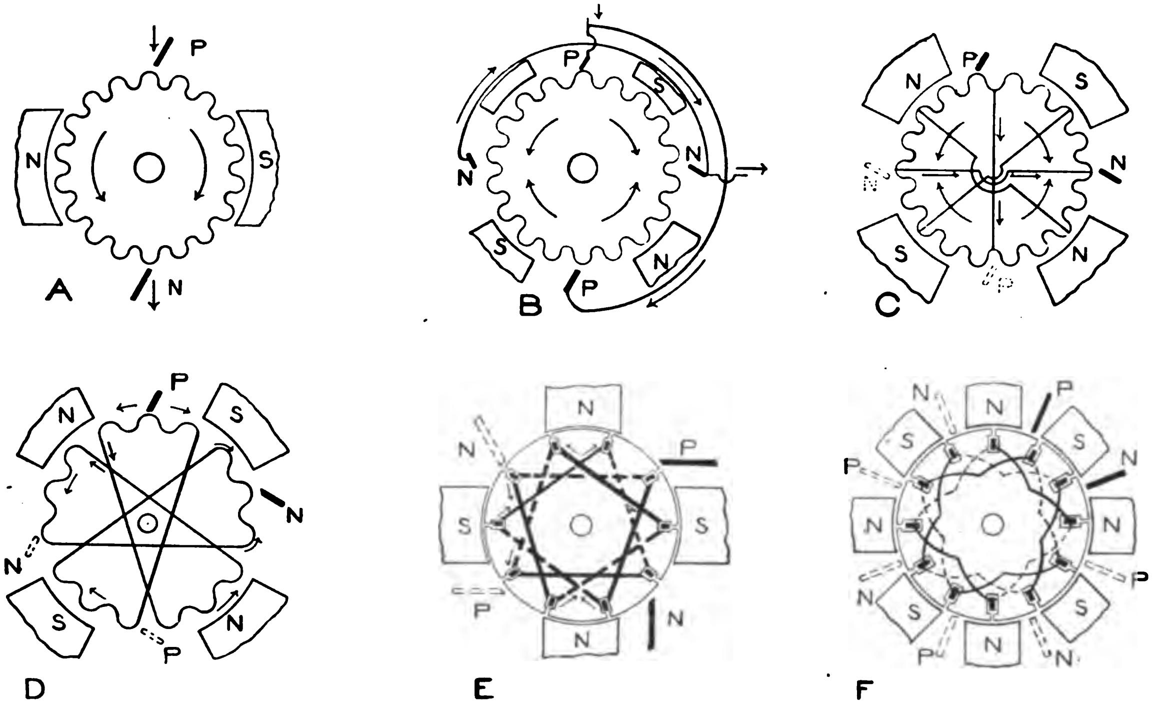
SYMPTOM. The magnetism and current are increased by shifting the brushes.

REMEDY. It often happens that the brushes are not set at the proper point; in fact, they may be set exactly wrong, so that the dynamo is incapable of generating any current whatever. This trouble is mainly due to the fact that the proper position for the brushes is not the same for all kinds of machines. Almost all ring armatures and many drum armatures require the brushes to be set opposite the *spaces* between the pole-pieces. But most armatures are wound so that the brushes must be set nearly 90° from this position, or opposite the center of the poles. Some multipolar machines have as many sets of brushes as there are pole pieces; while others have armatures that are cross-connected, or have the conductors arranged in series so that only two sets of brushes are required. Four-pole machines with only two brushes require them to be set at 90°; 6-pole machines, either 60° or 180°; 8-pole, either 45° or 135°; 10-pole, either 36°, 108°, or 180°; 12-pole, either 30°, 90°, or 150°; and 16-pole, either 22½°, 67½°, 112½°, or 157½°; and so on.

The fact is, that the proper position of the brushes depends upon the particular winding, internal connections, etc., and *no one should ever assume to know where to set the brushes* unless he is perfectly familiar with the particular type of machine. A blue print or other definite instructions should always be obtained and followed; and, if these are not available, the matter may be determined by careful trial. The proper position of brushes is the same for dynamos and motors, except that in the former the brushes are given a forward lead, that is, shifted a little in the direction of rotation, whereas motor brushes should be set a little backward. This shifting is necessitated by the armature reaction or the magnetizing effect of the armature current, which distorts the field magnetism.

The positions and number of brushes for each kind of armature are show in Fig. 67, which shows also the *arrangements of circuits* in each of the leading types.

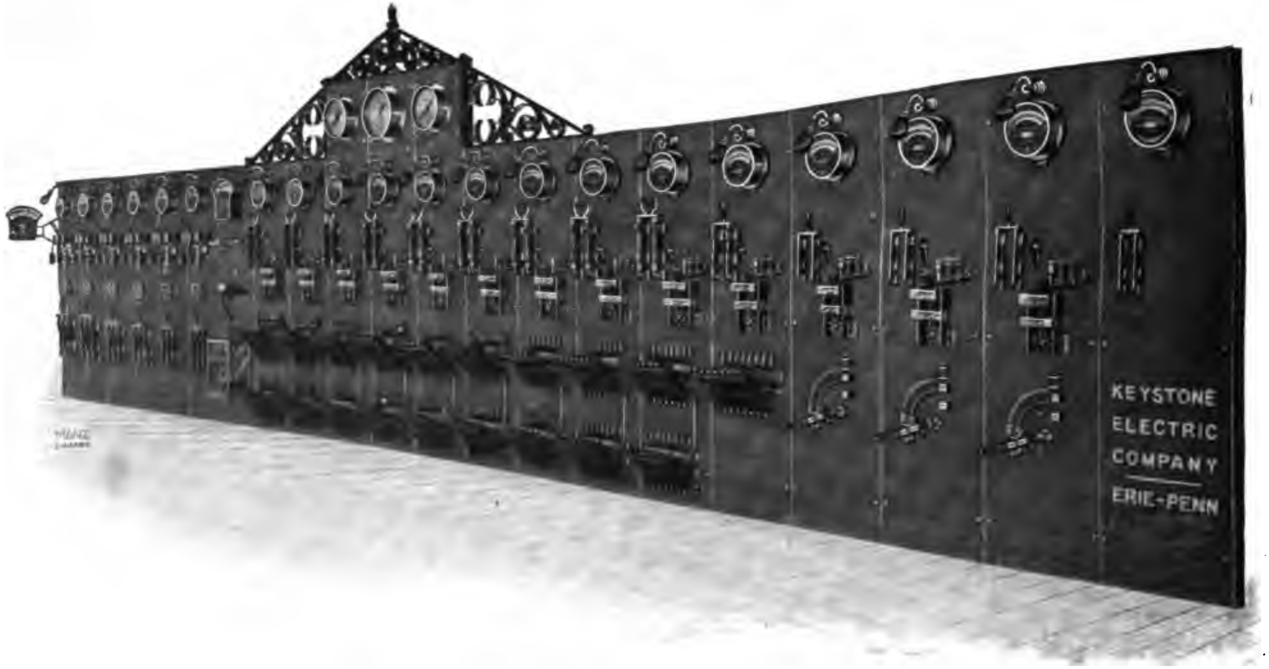
A is the armature for the ordinary two-pole machine, and may be drum- or ring-wound. The current enters from the positive



A = Two Pole, Two Circuit.
B = Four Pole, Four Circuit, Four Brushes in Multiple.
C = Four Pole, Four Circuit, Cross Connected, Two or Four Brushes in Multiple.

Fig. 67.

D = Four Pole, Two Circuit Ring, Two or Four Brushes in Multiple.
E = Four Pole, Two Circuit Drum, Two or Four Brushes in Multiple.
F = Eight Pole, Two Circuit Drum, Two, Four, Six, or Eight Brushes in Multiple.



SWITCHBOARD OF THE WHITEHALL PORTLAND CEMENT CO.

Built and Installed by the Keystone Electric Co.

UNIV. OF MICH.

brush, passes around both sides of the armature, and out through the negative brush. Hence this is called a "two-circuit" armature.

B is a plain armature used in a 4-pole machine. As there are here two more poles, it is necessary to use two more brushes to collect the current. This gives two brushes through which current enters, and two through which it leaves; consequently each pair of brushes must be joined in multiple in order to carry all the current to the mains.

C is a 4-pole armature in which the additional currents are carried across to the first pair of brushes by means of connections through the center of the armature. Therefore, the entire current may be taken off by these brushes; or two more may be added to divide the work, in which case they must also be connected in multiple to the first pair, as in case B above.

With either B or C, since there are two parts of the armature winding under the influence of different magnets, but running in parallel to the mains, it is evident that if the pressure of the current in one part of the winding is weaker than in the other, through inequality of the magnets or otherwise, it will short-circuit the other part of the winding and work badly.

This cannot occur in A, because both parts of the winding are influenced by the two ends of a single magnet.

D is a 4-pole armature in which the windings do not connect together in parallel but *in series*, thus overcoming the objection above. It has a ring-winding, and each coil is connected to the one diametrically opposite. An examination will show that though the poles alternate, the wire is all arranged so that the current flows in a single pair of circuits, as in A. This also permits of the use of larger wire and fewer turns, as they are connected in series instead of multiple.

E is a drum armature all in series, as in the case of D. Inspection will show that the actions of each of the four poles on all the bars harmonize, or cause the current to flow in the same direction.

To facilitate tracing the course of the current, the arrangement is represented with the smallest possible number of bars Many more are used in practice.

F is a series drum armature for eight poles. The principle is the same, but the limit of brush adjustment is smaller. The entire range from zero to full E. M. F. is covered by moving the brush one-eighth of the circumference.

As the winding is all in series, two brushes only are necessary; but as many more as desired may be added between the other poles, and then connected in multiple to the first ones. This is usually taken advantage of, because a single pair of brushes would become heated from carrying excessive current; but the difficulty of one part of the armature short-circuiting the other cannot occur, because *each part* of the winding is under the influence of all the poles.

X. VOLTAGE OF GENERATOR NOT RIGHT

VOLTAGE TOO LOW.

CAUSE 1. **Speed too low.** (See "Speed not Right.")

REMEDY. Increase speed of the prime mover, if possible; when this cannot be done, decrease the diameter of the driven pulley or increase the diameter of the driving pulley, preferably the latter.

CAUSE 2. **Field magnetism weak.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 8.)

CAUSE 3. **Brushes not in proper position.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 2.)

CAUSE 4. **Machine overloaded.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 1 and "Speed not Right," Cause 1); also increase field excitation, if possible.

CAUSE 5. **Short-circuited armature coil or coils.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 5.)

CAUSE 6. **Reversed armature coil or coils.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 5.)

VOLTAGE TOO HIGH.

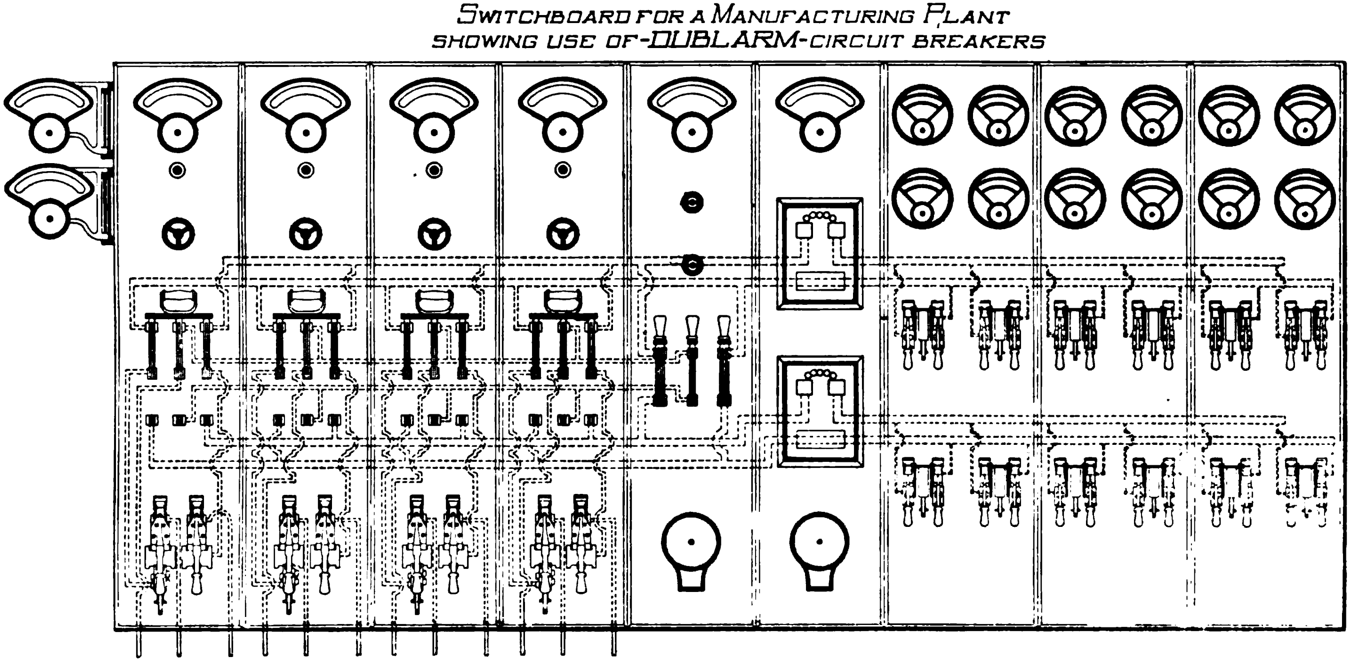
CAUSE 7. **Speed too high.**

REMEDY. Apply the reverse of treatment given in Cause 1.

CAUSE 8 **Field magnetism too powerful.**

REMEDY. Increase resistance of shunt field circuit, by means of a shunt field rheostat.

CAUSE 9. **Machine Compounds too much.**
REMEDY. Decrease resistance of series field shunt.
(See Compound-wound Dynamos, page 25, Part I.)


SWITCHBOARD FOR A MANUFACTURING PLANT
SHOWING USE OF -DUBLARM- CIRCUIT BREAKERS

SWITCHBOARD.

The Cutter Company

POWER STATIONS.

With the rapid increase of the use of electricity for power, lighting, traction, and electro-chemical processes, the power houses equipped for the generation of the electrical supply have increased in size from plants containing a few low-capacity dynamos, belted to their prime movers and lighting a limited district, to the modern central station, furnishing power to immense systems and over extended areas. Examples of the latter type of station are found at Niagara Falls, such stations as the Metropolitan and Manhattan stations in New York City, the plants of the Boston Edison Illuminating Company, etc.

The subject of the design, operation, and maintenance of central stations forms an extended and attractive branch of electrical engineering. The design of a successful station requires scientific training, extensive experience, and technical ability. Knowledge of electrical subjects alone will not suffice, as civil and mechanical engineering ability is called into play as well, while ultimate success depends largely on financial conditions. Thus, with unlimited capital, a station of high economy of operation may be designed and constructed, but the business may be such that the fixed charges for money invested will more than equal the difference between the receipts of the company and the cost of the generation of power alone. In such cases it is better to build a cheaper station and one not possessing such extremely high economy, but on which the fixed charges are so greatly reduced that it may be operated at a profit to the owners.

The designing engineer should be thoroughly familiar with the nature and extent of the demand for power and with the probable increase in this demand. Few systems can be completed for their ultimate capacity at first and, at the same time, operated economically. Only such generating units, with suitable reserve capacity, as are necessary to supply the demand should be installed at first, but all apparatus should be arranged in such a manner that future extensions can be readily made.

The subjects of power stations, as here treated, will consider the following general topics:

Location of station and substation, with choice of system to be employed.
Steam plants, boilers, piping, prime movers, etc.
Hydraulic plants.
The use of other prime movers.
The electrical plant, generators, and exciters, switching apparatus, etc.
Buildings.
Station records, methods of charging for power, etc.

LOCATION OF THE GENERATING STATION.

The choice of a site for the generating station is very closely connected with the selection of the system to be used, which system, in turn, depends largely on the nature of the demand, so that it is a little difficult to treat these topics separately. Several possible sites are often available, and we may either consider the requirements of an ideal location, selecting the available one which is nearest to this in its characteristics, or we may select the best system for a given area and assume that the station may be located where it would be best adapted to this system. Wherever the site may be, it is possible to select an efficient system, though not always an ideal one.

The following points should be considered in the location of a station, no matter what the system used:

1. **Accessibility.**
2. **Water supply.**
3. **Stability of foundation.**
4. **Surroundings.**
5. **Facility for extension.**
6. **Cost of real estate.**

The station should be readily accessible on account of the delivery of fuel and stores, and of the machinery, while it should be so located that ashes and cinders may be easily removed. If possible, the station should be located so as to be reached by both rail and water, though the former is generally more desirable. If the coal can be delivered to the bunkers directly from the cars, the very important item of the cost of handling fuel may be greatly reduced. Again, the station should be in such a location that it may be readily reached by the workmen.

Cheap and abundant water supply for both boilers and condensers is of utmost importance in locating a steam station. The quality of the water supply for the boiler is of more importance than the quantity. It should be as free as possible from impurities which are liable to corrode the boilers, and for this reason water from the town mains is often used, even when other water is available, as it is possible to economize in the use of water by the selection of proper condensers. The supply for condensing purposes should be abundant, otherwise it is necessary to install extensive cooling apparatus which is costly and occupies much space.

The machinery, as well as the buildings, must have stable foundations, and it is well to investigate the availability of such foundations when selecting the site.

In the operation of a power plant using coal or other fuels, certain nuisances arise, such as smoke, noise, or vibration, etc. For this reason it is preferable to locate where there is little liability to complaint on account of these causes, as some of these nuisances are costly and difficult or even impossible to prevent.

A station should be located where there are ample facilities for extension and, while it may not always be advisable to purchase land sufficient for these extensions at first, if there is the slightest doubt in regard to being able to purchase it later, it should be bought at once, as the station should be as free as possible from risk of interruption of its plans. Often real estate is too high for purchasing a site in the best location, and then the next best point must be selected. A consideration of all the factors involved is necessary in determining whether or not this cost is too high. In densely populated districts it is necessary to economize greatly with the space available, but it is generally desirable that the machinery may all be placed on the ground floor and that adequate provision may be made for the storage of fuel, etc.

The location of substations is usually fixed by other conditions than those which determine the site of the main power house. Since, in the simple rotary converter substation, neither fuel or water are necessary and there is little noise or vibration, it may be located wherever the cost of real estate will permit, provided suitable foundation may be constructed. The distance between substations depends entirely on the selection of the system and the nature of the service.

Where low voltages are used it is essential that the station be located as near the center of the system as possible. This center is located as follows:

Having determined the probable loads and their points of application for the proposed system, these loads are indicated on a drawing with the location of the same shown to scale. The center of gravity of this system, considering each load as a weight, is then found and its location is the ideal location, as regards amount of copper necessary for the distributing system.

Consider Fig. 1, which shows the location of five different loads, which in this case are indicated by number of amperes. Combining loads A and B, we have $Ax = By$. $x + y = a$. Solving these equations we find that A and B may be considered as a load of A + B amperes at F. Similarly, C and D, E and F, and G and H may be combined giving us I, the center of the system. The amount of copper necessary for a given regulation runs up very rapidly as the distance of the station from this point increases.

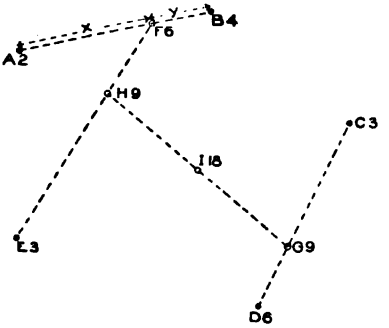


Fig. 1.

Selection of System. General rules only can be stated for the selection of a system to be used in any given territory for a certain class of service.

For an area not over two miles square and a site reasonably near the center, for lighting and ordinary power purposes, direct-current, low-pressure, three-wire systems may be used. Either 220 or 440 volts may be used as a maximum voltage, and motors should, preferably, be connected across the outside wires of the circuits. Five-wire systems with 440 volts maximum potential have been used, but they require very careful balancing of the load if the service is to be satisfactory. 220-volt lamps are giving good satisfaction; moderate-size, direct-current motors may be readily built for this pressure and constant-potential arc lamps may be operated on this voltage though not so economically as on 110 volts, if single lamps are used. For direct-current railway work, the limit of the distance to which power may be economically delivered with an initial pressure of 600 volts is from five to seven miles, depending on the traffic.

If the area to be served is materially larger than the above, or distances for direct-current railways greater, either of two different schemes may be adopted. Several stations may be located in the territory and operated separately or in multiple on the various loads, or one large power house may be erected and the energy transmitted from this station at a high voltage to various transformers or transformer substations which, in turn, transform the voltage to one suitable for the receivers. Local conditions usually determine which of these two shall be used.

The use of several low-tension stations operating in multiple is recommended only under certain conditions, namely, that the demand is very heavy and fairly uniformly distributed throughout the area, and suitable sites for the power house can be readily obtained. Such conditions rarely exist and it is a question whether or not the single station would not be just as suitable for such cases as where the load is not so congested.

One reason why a large central station is preferred to several smaller stations is that large stations can be operated more economically, owing to the fact that large units may be used and they can be run more nearly at full load. There is a gain in the cost of attendance, and labor-saving devices can be more profitably installed. The location of the power plant is not determined to such a large extent by the position of the load, but other conditions, such as water supply, cheap real estate, etc., will be the governing factors. In several cities, notably New York and Boston, large central stations are being installed to take the place of several separate stations, the old stations being changed from generating power houses to rotary-converter substations. Both direct-current low-tension machines, to supply the neighboring districts, and high-tension alternating-current, for supplying the outlying or residence districts, are often installed in the one station.

As examples of the central station being located at some distance from the center of the load, we have nearly all of the large hydraulic power developments. Here it is the cheapness of the water power which determines the power house location. The greatest distance over which power is transmitted electrically at present is in the neighborhood of 200 miles.

If a high-tension alternating-current system is to be installed, there remains the choice of a polyphase or single-phase machine as well as the selection of voltage for transmission purposes. As pointed out in "Power Transmission", polyphase generators are cheaper than single-phase generators and, if necessary, they can be loaded to about 80% of their normal capacity, single-phase, while motors can be more readily operated from polyphase circuits. If synchronous motors or rotary converters are to be installed, a polyphase system is necessary. The voltage will be determined by the distance of transmission, care being taken to select a value considered as standard, if possible. Generators are wound giving a voltage at the terminals as high as 15,000 volts, but in many districts it is desirable to use step-up transformers for voltages above 6,600 on account of liability to troubles from lightning.

With the development of the single-phase railway motor, central stations generating single-phase current only, will be built in larger sizes than previously, as their use heretofore has been limited to lighting stations.

Size of Plant. A few general notes in regard to the design of plants will be given here, the several points being taken up more in detail later.

Direct driving of apparatus is always superior to methods of gearing or belting as it is efficient, safe, and reliable, but it is not as flexible as shafting and belts. and on this account its adoption is not universal.

Speeds to be used will depend on the type and size of the generating unit. Small machines are always cheaper when run at high speeds, but the saving is less on large generators. For large engines, slow speed is always preferable.

It is desirable that there be a demand for both power and lighting, and a station should be constructed which will serve both purposes. The use of power will create a day load for a lighting station which does much to increase its ultimate efficiency and, as a rule, its earning capacity.

In addition to generator capacity necessary to supply the load, a certain amount of reserve, either in the way of additional units or overload capacity, must be installed. The probable load for say three years can be closely estimated and this, together with the proper reserve, will determine the size of the station. The plant as a whole, including all future extensions, should be planned at the start as extensions will then be greatly facilitated. Usually it will not be desirable to begin extensions for at least three years after the first part of the plant has been erected.

Enough units must be installed so that one or more may be laid off for repairs, and there are several arguments in favor of making this reserve in the way of overload capacity, for the generators at least. Some of these arguments are: Reserve is often required at short notice, notably in railway plants. With overload capacity, rapid increase of load, such as occurs in lighting stations when darkness comes on suddenly, may be more readily taken care of. There is always a factor of safety in machines not running to their fullest capacity. Reserve capacity is cheaper in this form than if installed as separate machines. As a disadvantage, we have a lower efficiency, due to machines not usually running at full load, but in the case of generators this is very slight.

With an overload capacity of 33⅓%, four machines should be the initial installment since one can be laid off for repairs if necessary, the total load being readily carried by three machines. In planning extensions, the fact that at least one machine may require to be laid off at any time should not be lost sight of, while the units should be made as large as is conducive to the best operation.

TABLE 1.

Permissible Overload 33 per cent.

	Machines added one at a time.		Machines added two at a time.		Machines added three at a time.	
	No.	Size.	No.	Size.	No.	Size.
Initial installment	4	500	4	500	4	500
First extension	1	666	2	1000	3	2000
Second "	1	888	2	2000	5	5000
Third "	1	1183	2	4000	4	5000
Fourth "	1	1577	4	4000		
Fifth "	1	2103	8	4000		
Sixth "	1	2804				

Table 1 is worked out showing the initial installment for a 2,000-K.W. plant with future extensions. It is seen from this table that adding two machines at a time gives more uniformity in the size of units—a very desirable feature.

The boilers should be of large units for stations of large capacity, while for small stations they must be selected so that at least one may be laid off for repairs.

STEAM PLANT.

BOILERS.

The majority of power stations have their machinery driven by either steam or water power, though there are many using gas engines as prime movers. If a steam plant is being considered, one of the first subjects to be taken up is the generation of the steam. The subject of boilers is one of vital importance to the successful operation of steam-driven central stations. The object of the boiler with its furnace is to abstract as much heat as possible from the fuel and impart it to the water. The various kinds of boilers used for accomplishing this more or less successfully are described in books on boilers, and we will consider here the merits of a few of the types only as regards central-station operation.

The requirements are: *First*, that steam be available throughout the twenty-four hours; the amount required at different parts of the day varying considerably. Thus, in a lighting station, the demand from midnight to 6 a. m. is very light, but toward evening, when the load on the station increases very rapidly, there is an abrupt increase in the rate at which steam must be given off. The maximum demand can be readily anticipated under normal weather conditions, but occasionally this maximum will be equaled or even exceeded at unexpected moments. For this reason a certain number of boilers must be kept under steam constantly, more or less of them running with banked fires during light loads. If the boilers have a small amount of radiating surface, the loss during idle hours will be decreased.

Second, the boilers must be economical over a large range of rates of firing and must be capable of being forced without detriment. Boilers should be provided which work economically for the hours just preceding and following the maximum load while they may be forced, though running at lower efficiency, during the peak.

Third, coming to the commercial side of the question, we have first cost, cost of maintenance, and space occupied. The first cost, as does the cost of maintenance, varies with the type and pressure of the boiler. The space occupied enters as a factor only when the situation of the station is such that space is limited, or when the amount of steam piping becomes excessive. In some city plants, space may be the determining feature in the selection of boilers.

The **Cornish and Lancashire** boilers differ only in the number of cylindrical tubes in which furnaces are placed. As many as three tubes are placed in the largest sizes (seldom used) of the Lancashire boilers. They are made up to 200 pounds steam pressure and possess the following features:

1. High efficiency at moderate rates of combustion.
2. Low rate of depreciation.
3. Large water space.
4. Easily cleaned.
5. Large floor space required.
6. Cannot be readily forced.

The Galloway boiler differs from the Lancashire boiler in that there are cross tubes in the flues.

In the **Multitubular boiler** the number of tubes is greatly increased and their size diminished. Their heating surface is large and they steam rapidly. They are used extensively for power-station work.

The chief characteristics of the **water-tube boilers,** of which there are many types, are:

1. Moderate floor space.
2. Ability to steam rapidly.
3. Good water circulation.
4. Adapted to high pressure.
5. Easily transported and erected.
6. Easily repaired.
7. Not easily cleaned.
8. Rate of deterioration greater than for Lancashire boiler.
9. Small water space, hence variation in pressure with varying demands for steam.
10. Expensive setting.

Marine boilers require no setting. Among their advantages and disadvantages may be mentioned:

1. **Exceedingly small space necessary.**
2. **Radiating surface reduced.**
3. **Good economy.**
4. **Heavy and difficult to repair.**
5. **Unsuitable for bad water.**
6. **Poor circulation of water.**

Another type of boiler, known as the Economic, is a combination of the Lancashire and multitubular boilers, as is the marine boiler. It is set in brickwork and arranged so that the gases pass under the bottom and along the sides of the boiler as well as through the tubes. It may be compared with other boilers from the following points:

1. **Small floor space.**
2. **Less radiating surface than the Lancashire boiler.**
3. **Not easily cleaned.**
4. **Repairs rather expensive.**
5. **Requires considerable draft.**

As regards first cost, boilers installed for 150 pounds pressure and the same rate of evaporation, will run in the following order: Galloway and Marine, highest first cost, Economic, Lancashire, Babcock & Wilcox. The increase of cost, with increase of steam pressure, is greatest for the Economic and least for the water-tube type.

Deterioration is less with the Lancashire boiler than with the other types.

The floor space occupied by these various types built for 150 pounds pressure and 7,500 pounds of water, evaporated per hour, is given in Table 2.

TABLE 2.

Kind of Boiler.	Floor Space in Sq. Ft.
Lancashire	408
Galloway	371
Babcock and Wilcox	200
Marine wet-back	120
Economic	210

The percentage of the heat of the fuel utilized by the boiler is of great importance, but it is difficult to get reliable data in regard to this. Table 3 is taken from Donkin's "Heat Efficiency of Steam Boilers", and will give some idea of the efficiencies of the different types. Economizers were not used in any of these tests, but they should always be used with the Lancashire type of boiler.

TABLE 3.

Kind of Boiler.	No. of Experiments.	Mean Efficiency of two best Experiments.	Lowest Efficiency.	Mean Efficiency of all Experiments.
Lancashire hand-fired	107	79.5	42.1	62.3
Lancashire machine-fired	40	73.0	51.9	64.2
Cornish hand-fired	25	81.7	53.0	68.0
Babcock and Wilcox hand-fired	49	77.5	50.0	64.9
Marine wet-back hand-fired	6	69.6	62.0	66.0
Marine dry-back hand-fired	24	75.7	64.7	69.2

It is well to select a boiler from 20 to 50 pounds in excess of the pressure to be used, as its life may thus be considerably extended, while, when the boiler is new, the safety valve need not be set so near the normal pressure, and there is less steam wasted by the blowing off of this valve. Again, a few extra pounds of steam may be carried just previous to the time the peak of the load is expected. For pressures exceeding 200 or, possibly, 150 pounds, a water-tube boiler should be selected.

In large stations, it is preferable to make the boiler units of large capacity, to do away as much as possible with the extra piping and fittings necessary for each unit. Water-tube boilers are best adapted for large sizes. These may be constructed for 150 pounds pressure, large enough to evaporate 20,000 pounds of water per hour, at an economical rate.

To sum up—For stations of moderate size and with medium pressures with plenty of space, use Lancashire or fire-tube boilers; for high pressure or large units, select water-tube boilers; where space is limited, install marine boilers, although they are not as safe as water-tube boilers for high pressures.

Steam Piping. The piping from the boilers to the engines should be given very careful consideration. Steam should be available at all times and for all engines. Freedom from serious interruptions due to leaks or breaks in the piping is brought about by very careful design and the use of good material in construction. Duplicate piping is used in many instances. Provision must always be made for variations in length of the pipe with variation of temperature. For plants using steam at 150 pounds pressure, the variation in the length of steam pipe may be as high as 2.5

inches for 100 feet, and at least 2 inches for 100 feet should always be counted upon.

Arrangement. Fig. 2 shows a simple diagram of the "ring" system of piping. The steam passes from the boiler by two paths to the engine and any section of the piping may be cut out by the closing of two valves. Simple ring systems have the following characteristics:

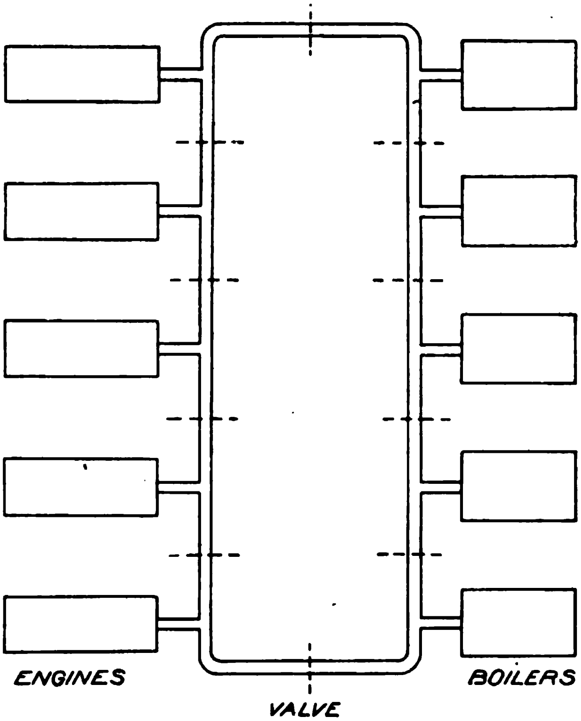
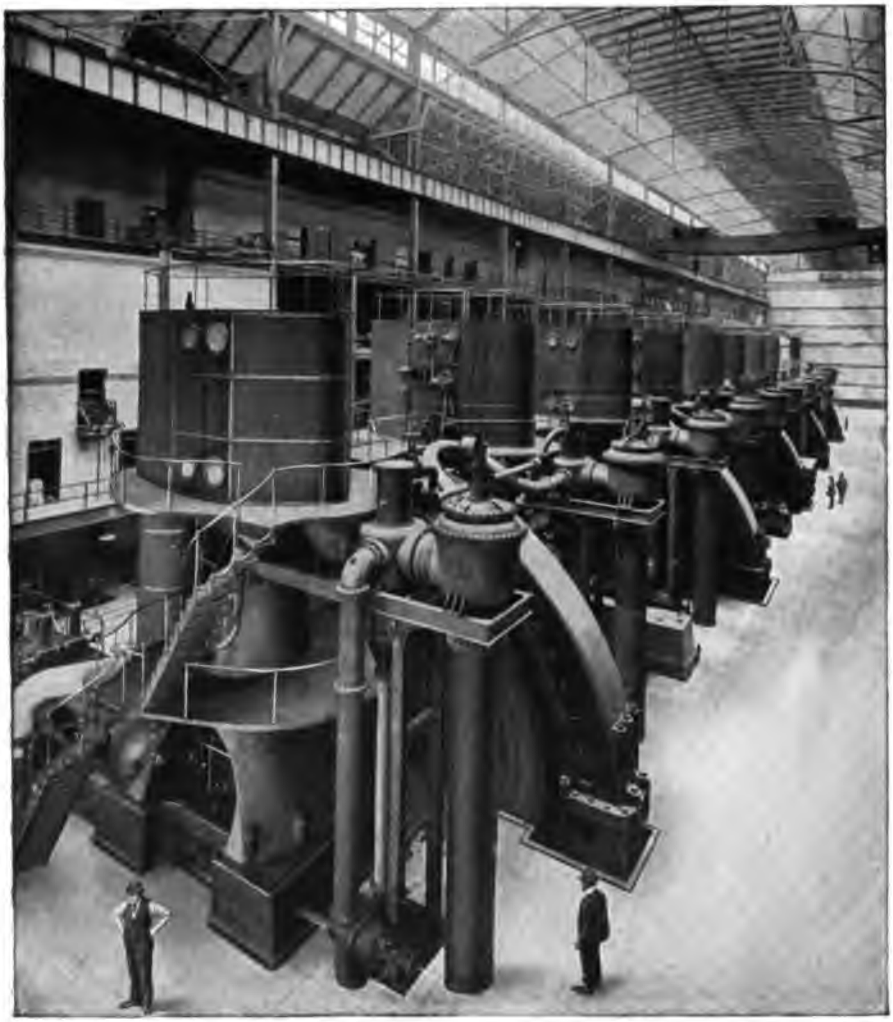


Fig. 2.

1. The range, as the main pipe is called, must be of uniform size and large enough to carry all of the steam when generated at its maximum rate.
2. A damaged section may disable one boiler or one engine.
3. Several large valves are required.
4. Provision may be readily made to allow for expansion of pipes.

Cross connecting the ring system, as shown in Fig. 3, changes these characteristics as follows:

1. Size of pipes and consequent radiating surface is reduced.
2. More valves needed but they are of smaller size.
8. Less easy to arrange for expansion of the pipes.



POWER HOUSE OF NEW YORK SUBWAY.

Showing Five of the Nine 12,000 Horse-Power Allis-Chalmers Engines.

If the system is to be duplicated, that is, two complete sets of main pipes and feeders installed (see Fig. 4), two schemes are in use:

1. Each system is designed to operate the whole station at maximum load with normal velocity and loss of pressure in the pipes, and only one system is in use at a time. This has the disadvantage that the idle section is liable not to be in good operating condition when needed. Large pipes must be used for each set of mains.

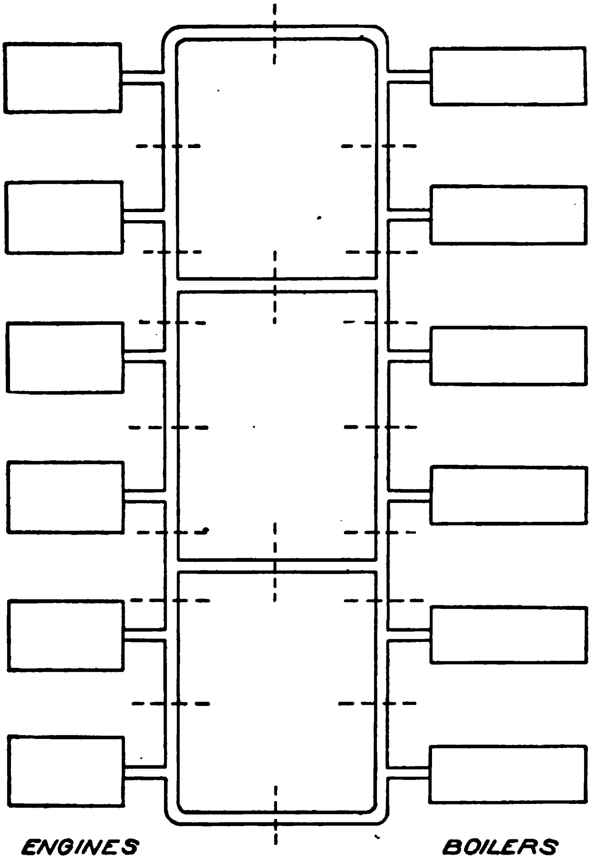


Fig. 3.

2. The two systems may be made large enough to supply steam at normal loss of pressure when both are used at the same time, while either is made large enough to keep the station running should the other section need repairs. This has the advantages of less expense, and both sections of pipe are normally in use; but it has the disadvantages of more radiating surface to the pipes and consequent condensation for the same capacity for furnishing steam.

Complete interchangeability of units cannot be arranged for if the separate engine units exceed 400 to 500 horse power. Since engine units can be made larger than boiler units, it becomes necessary to treat several boiler units as a single unit, or battery, these batteries being connected as the single boilers already shown. For still larger plants the steam piping, if arranged to supply any engines from any batteries of boilers, would be of enormous size. If the boilers do not occupy a greater length of floor space than the engines, Fig. 5 shows a good arrangement of units. Any engine can be fed from either of two batteries of boilers and the liability of serious interruptions of service due to steam pipes or boiler trouble is very remote.

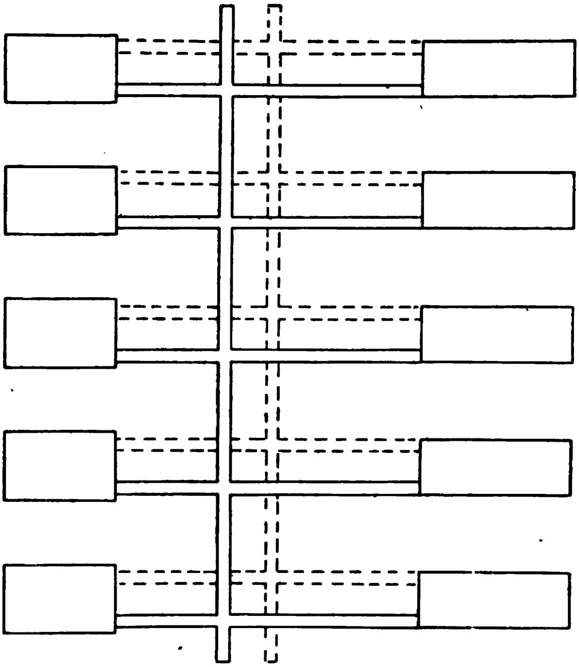


Fig. 4.

Material. Steel pipe, lap welded and fastened together by means of flanges, is to be recommended for all steam piping. The flanges may be screwed on the ends of sections and calked so as to render this connection steam tight, though in large sizes it is better to have the flanges welded to the pipes. This latter construction costs no more for large pipes and is much more reliable. All valves and fittings are made in two grades or weights, one for low pressures, and the other for high pressures. The high-pressure fittings should always be used for electrical stations. Gate valves should always be selected and, in large sizes, they should be provided with a by-pass.

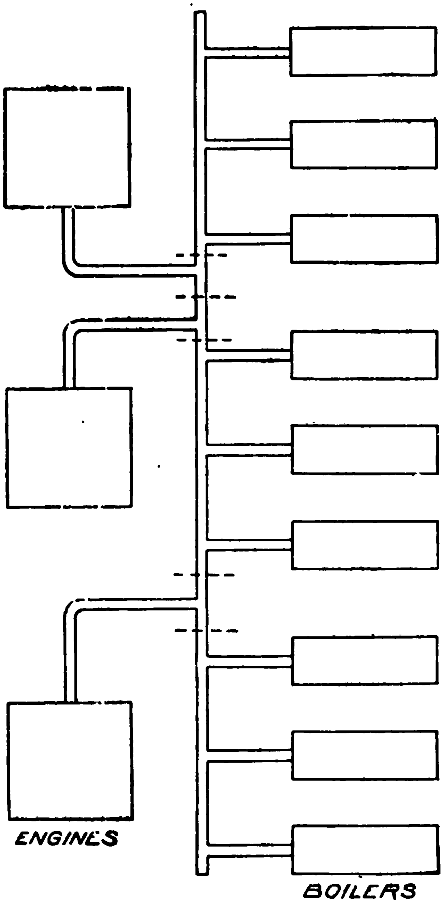


Fig. 5.

Asbestos, either alone or with copper rings, vulcanized india rubber, asbestos and india rubber, etc., are used for packing between flanges to render them steam tight. Where there is much expansion, the material selected should be one that possesses considerable elasticity. Joints for high-pressure systems require much more care than those where steam is used at a low pressure, and the number of joints should be reduced to a minimum by using long sections of pipe.

A list of the various fittings required for steam piping, together with their descriptions, is given in books on boilers. One precaution to be taken is to see that such fittings do not become too numerous or complicated, and it is well not to depend too much on automatic fittings. Steam separators should be large enough to serve as a reservoir of steam for the engine and thus equalize, to a certain extent, the velocity of flow of steam in the pipes.

In providing for the expansion of pipes due to change of temperature, "U" bends made of steel pipe and having a radius of curvature not less than six times, and preferably ten times the diameter of the pipe, are preferred. Copper pipes cannot be recommended for high pressures, while slip expansion joints are most undesirable on account of their liability to bind.

The size of steam pipes is determined by the velocity of flow. Probably an average velocity of 60 feet per second would be better than 100 feet per second, though in some cases where space is limited a velocity as high as 150 feet per second has been used.

The loss in pressure in steam pipes may be obtained from the following formula:

$$p_1 - p_2 = \frac{Q^2 w L}{c^2 d^5}$$

where $p_1 - p_2$ = loss in pressure in pounds per sq. in.
Q = quantity of steam in cu. ft. per minute.
d = diameter of pipe in inches.
L = length in feet.
w = weight per cu. ft. of steam at pressure p_1.
c = constant depending on size of pipe.

Values of c are as follows:

Diameter of pipe..	½"	1"	2"	3"	4"	5"	6"	7"	8"	9"	10"
Value of c.........	36.8	45.3	52.7	56.1	57.8	58.4	59.5	60.1	60.7	61.2	61.8
Diameter of pipe...............					12"	14"	16"	18"	20"	22"	24"
Value of c.....................					62.1	62.3	62.6	62.7	62.9	63.2	63.2

In mounting the steam pipe, it should be fastened rigidly at one point, preferably near the center of a long section, and allowed a slight motion longitudinally at all other supports. Such supports may be provided with rollers to allow for this motion, or the pipe may be suspended from wrought-iron rods which will give a flexible support. Practice differs in the location of the steam piping, some engineers recommending that it be placed underneath the engine room floor and others that it be located high above the engine room floor. In any case it should be made easily accessible, and the valves should be located so that nothing will interfere with their operation. Proper provision must be made for draining the pipes.

All piping as well as joints should be carefully covered with a good quality of lagging as the amount of steam condensed in a bare pipe, especially if of any great length, is considerable. In selecting a lagging the following points should be noticed. Covering for steam pipes should be incombustible, should present a smooth surface, should not be easily damaged by vibration or steam, and should have as large a resistance to the passage of heat as possible. It must not be too thick, otherwise the increased radiating surface will counterbalance the resistance to the passage of heat.

The loss of power in steam pipes due to radiation is given as follows:

$H = .262rLd.$
H = loss of power in heat units.
d = diameter of pipe.
L = length of pipe in feet.
r = constant depending on steam pressure and pipe covering.

Steam pressure in pounds (absolute)	40	65	90	115
Values of r for uncovered pipe	437	555	620	684
Value of r for pipe covered with 2 inches of hair felt	48	58	66	73

Referring to table in books on boilers, the relative values of different materials used for covering steam pipes may be found.

Superheated Steam reduces condensation in the engines as well as in the piping, and increases the efficiency of the system. Its use was abandoned for several years, due to difficulties in lubricating and packing the engine cylinders, but by the use of mineral oils and metallic packing, these difficulties have been done away with to a large extent, while steam turbines are especially adapted to the use of superheated steam. The application of heat directly to steam, as is done in the superheater, increases the efficiency of the boilers. Table 4 shows the increase in boiler efficiency for a certain boiler test, the results being given in pounds of water changed to dry, saturated steam. Tests on various engines show a gain in efficiency as high as 9% with a superheat of 80° to 100° F, while special tests in some cases show even a greater gain.

TABLE 4.

Amount of superheat.	Water evaporated per lb. of coal.	
	Without superheat.	With superheat.
40 degrees F.	7.82	9.99
42 "	6.42	7.06
55 "	6.00	7.00
56.5 "	6.78	8.66
55.2 "	7.15	8.65

Superheaters are very simple, consisting of tubular boilers containing steam instead of water, and either located so as to utilize the heat of the gases, the same as economizers, or separately fired. They should be arranged so that they may be readily cut out of service, if necessary, and provision must be made for either flooding them or turning the hot gases into a by-pass, as the tubes would be injured by the heat if they contained neither water nor steam.

FEED WATER AND FEEDING APPLIANCES.

All water, such as can be obtained for the feeding of boilers, contains some impurities, among the most important of which as regards boilers are soluble salts of calcium and magnesium. Bicarbonates of the alkaline earths cause precipitations on the interior of boilers, forming "scale". Sulphate of lime is also deposited by concentration under pressure. Scale, when formed, not only decreases the efficiency of the boiler but also causes deterioration, for if sufficiently thick, the diminished conducting power of the boiler allows the tubes or plates to be overheated and to crack or burst. Again, the scale may keep the water from contact with sections of the heated plates for some time and then, giving way, large volumes of steam are generated very quickly and an explosion may result.

Some processes to prevent the formation of scale are used, which affect the water after it enters the boilers, but they are not to be recommended, and any treatment the water receives should affect it previous to its being fed to the boilers. Carbonates and a small quantity of sulphate of lime may be removed by heating in a separate vessel. Large quantities of sulphate of lime must be precipitated chemically.

Sediment, small particles of matter in suspension, must be removed by allowing the water to settle. Vegetable matters are sometimes present, which cause a film to be deposited. Certain gases, in solution—such as oxygen, nitrogen, etc.—cause pitting of the boiler. This effect is neutralized by the addition of chemicals. Oil, from the engine cylinder, is particularly destructive to boilers and. when present in the condensed steam must be carefully removed.

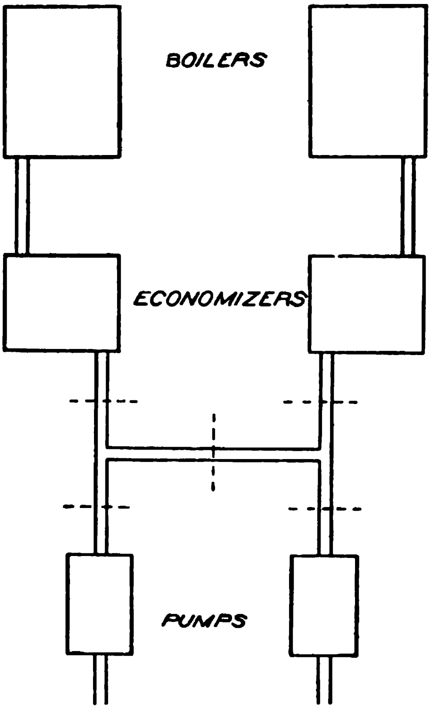


Fig. 6.

Both feed pumps and injectors are used for feeding the water to the boilers. Feed pumps may be either steam or motor-driven. Steam-driven pumps are very inefficient, but they are simple and the speed is easily controlled. Motor-driven pumps are more efficient and neater, but more expensive and more difficult to regulate efficiently over a wide range of speed. Direct-acting pumps may have feed-water heaters attached to them, thus increasing the efficiency of the apparatus as a whole. The supply of electrical energy must be constant if motor-driven pumps are to be used.

Feed pipes must be arranged so as to reduce the risk of failure to a minimum, and for this reason they are almost always duplicated. More than one water supply is also recommended if there is the slightest danger of interruption on this account. One common arrangement of feed-water apparatus is to install a few large pumps supplying either of two mains from which the boiler con-

TABLE 5.

Giving Rate of Flow of Water, in Feet per Minute, through Pipes of Various Sizes, for Varying Quantities of Flow.

Gallons per Min.	¾ in.	1 in.	1¼ in	1½ in.	2 in.	2½ in.	3 in.	4 in.
5	218	122½	78½	54½	30½	19½	13½	7⅔
10	436	245	157	109	61	38	27	15⅓
15	653	367½	235½	163½	91½	58½	40½	23
20	872	490	314	218	122	78	54	30⅔
25	1090	612½	392½	272½	152½	97½	67½	38⅓
30		735	451	327	183	117	81	46
35		857½	549½	381½	213½	136½	94½	53⅔
40		980	628	436	244	156	108	61⅓
45		1102½	706½	490½	274½	175½	121½	69
50			785	545	305	195	135	76⅔
75			1177½	817½	457½	292½	202½	115
100				1090	610	390	270	153⅓
125					762½	487½	337½	191⅔
160					915	585	405	230
175					1067½	682½	472½	268⅓
200					1220	780	540	306⅔.

nections are taken. This is a complicated and costly system of piping. Fig. 6 shows a scheme used for feeding two boilers in which each pump is capable of supplying both boilers. Pipes should be ample in cross-section, and, in long lengths, allowance must be made for expansion. Cast iron or cast steel is the material used for their construction, while the joints are made by means of flanges fitted with rubber gaskets.

Table 5 gives the rate of flow of water in feet per minute through pipes of various sizes. A flow of 10 gallons per minute for each 100 H. P. of boiler equipment should be allowed without causing an excessive velocity of flow in the pipes.

BOILER FOUNDATIONS, FURNACES AND DRAFT.

The economical use of coal depends, to a large extent, on the setting of the boiler and proper dimensions of the furnaces. Internally-fired boilers require support only, while the setting of externally-fired boilers requires provision for the furnaces. Common brick, together with fire brick for the lining of portions exposed to the hot gases, are used almost invariably for boiler settings. It is customary to set the boiler units up in batteries of two, using a 20-inch wall at the sides and a 12-inch wall between the two boilers. The instructions for settings furnished by the manufacturers should be carefully followed out as they are based on conditions which give the best results in the operation of their boilers.

Natural Draft is the most commonly used and is the most satisfactory under ordinary circumstances. In determining the size of the chimney necessary to furnish this draft, the following formula is given by Kent:

$$A = \frac{.06\ F}{\sqrt{h}} \text{ or } h = \left(\frac{.06\ F}{A}\right)^2$$

A = area of chimney in sq. ft.
h = height of chimney in ft.
F = pounds of coal per hour.

The height of chimney should be assumed and the area calculated, remembering that it is better to have the chimney too large than too small.

The chimney may be of either brick or iron, the latter having a less first cost but requiring repairs at frequent intervals. General rules for the design of a chimney may be given as follows: The external diameter of the base should not be less than $\frac{1}{10}$ of the height. Foundations must be of the best. Interiors should be of uniform section and lined with fire brick. There must be an air space between the lining and chimney proper. The exterior should have a taper of from $\frac{1}{16}$ to $\frac{1}{4}$ inch to the foot. Flues should be arranged symmetrically.

Fig. 7 shows the construction of a brick chimney of good design, this chimney being used with boilers furnishing engines which develop 14,000 H. P.

Mechanical Draft is a term which may be used to embrace both forced and induced draft. The different systems of mechanical draft are described in books on boilers. The first cost of mechanical-draft systems is less than that of a chimney, but the operation and repair are much more expensive and there is always the risk of break-down. Artificial draft has the advantage that it can be varied within large limits and it can be increased to any desired extent, thus allowing the use of low grades of coal.

Firing of Boilers and Handling of Fuel. Coal is used for fuel to a greater extent than any other material, though oil, gas, wood, etc., are used in some localities. Local conditions, such as availability, cost, etc., should determine the material to be used and no general rules can be given. Data regarding the relative heating values of different fuels show the following general figures: One pound of petroleum, about $\frac{1}{7}$ of a gallon, is equivalent, when used with boilers, to 1.8 pounds of coal and there is less deterioration of the furnace with oil. $7\frac{1}{2}$ to 12 cubic feet of natural gas are required as the equivalent of one pound of coal, depending on the quality of the gas. $2\frac{1}{2}$ pounds of dry wood is assumed as the equivalent of one pound of coal.

When coal is used, it requires stoking and this may be accomplished either by hand or by means of mechanical stokers, many forms of which are available. Mechanical stoking has the advantage over hand stoking that the fuel may be fed to the furnace more uniformly and the fires and boilers are not subjected to sudden blasts of cold air as is the case when the fire doors are opened; a poorer grade of coal may be burned, if necessary, and the trouble due to smoke is much reduced. It may be said that mechanical stokers are used almost universally in the more important elec-

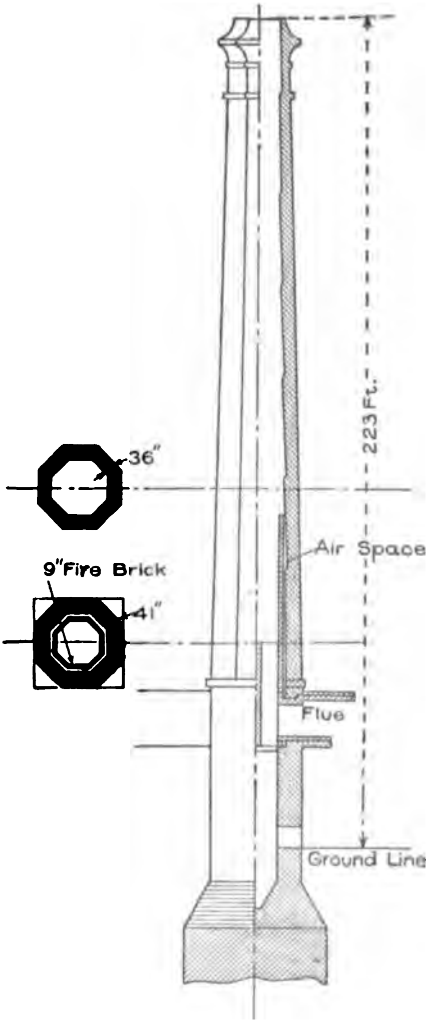


Fig. 7.

trical plants. Economic use of fuel requires great care in firing, especially if it is done by hand.

Where gas is used, the firing may be made nearly automatic, and the same is true of oil firing, though the latter requires more complicated burners, as it is necessary that the oil be vaporized.

In large stations, operated continuously, it is desirable that, as far as possible, all coal and ashes be handled by machinery, though the difference in cost of operation should be carefully considered before installing extensive coal-handling machinery. Machinery for automatically handling the coal will cost from $7.50 to $10 per horse-power rating of boilers for installation, while the ash-handling machinery will cost from $1.50 to $3.00 per horse power.

The coal-handling devices usually consist of chain-operated conveyors which hoist the coal from railway cars, barges, etc., to overhead bins from which it may be fed to the stokers. The ashes may be handled in a similar manner, by means of scraper conveyors, or small cars may be used. Either steam or electricity may be used for driving this auxiliary apparatus.

It is always desirable that there be generous provision for the storage of fuel sufficient to maintain operations of the plant over a temporary failure of supply.

STEAM ENGINES AND TURBINES.

The choice of steam prime movers is one which is governed by a number of conditions which can be treated but briefly here. The first of these conditions relates to the speed of the engine to be used. There is considerable difference of opinion in regard to this as both high and low-speed plants are in operation, which are giving good satisfaction. Slow-speed engines have a higher first cost and a higher economy. Probably in sizes up to 250 K.W. the generator should be driven by high-speed engines, above which the selection of either type will give satisfaction until sizes of say above 500 indicated horse power, when the slow-speed type is to be recommended. Drop valves cannot be used with satisfaction for speeds above about 100 revolutions per minute, hence high-speed engines must use direct-driven valve gears, usually governed by shaft governors. Corliss valves are used on nearly all slow-speed engines.

The steam pressure used should be at least 125 pounds per square inch at the throttle and a pressure as high as 150 to 160 pounds is to be preferred.

Close regulation and uniform angular velocity are required for driving generators, especially alternators which are to operate in parallel. This means sensitive and active governors, carefully designed fly-wheels and proper arrangement of cranks when more than one is used.

For large plants or plants of moderate size, compound condensing engines are almost universally installed. The advantage of these engines in increased economy are in part counterbalanced by higher first cost and increased complications, together with the pumps and added water supply necessary for the condensers. The approximate saving in amount of steam is shown in table 6, which applies to a 500 horse-power unit.

TABLE 6.

Engine.	Pounds of Steam per H. P. hour.
Simple non-condensing	30
Simple condensing	22
Compound non-condensing	24
Compound condensing	16

Triple expansion engines are seldom used for driving electrical machinery as their advantages under variable loads are doubtful. Compound engines may be tandem or cross compound and either horizontal or vertical. The use of cross-compound engines tends to produce uniform angular velocity, but the cylinder should be so proportioned that the amount of work done by each is nearly equal. A cylinder ratio of about 3½ to 1 will approximate average conditions. Either vertical or horizontal engines may be installed, each having its own peculiar advantages. Vertical engines require less floor space, while horizontal engines have a better arrangement of parts. Either type should be constructed with heavy parts and erected on solid foundations.

Recently steam turbines have come into use, and the number of stations at present under process of design or construction which will use steam turbines is very large. Several types of turbines are described in the books on engines. In addition to these, a short review of the Curtis turbine will not be out of place since this is one of the types which is coming into extended use.

The Curtis turbine is divided into sections, each section of which may contain one, two, or more, revolving sets of buckets and stationary vanes supplied with steam from a set of expansion nozzles. By this arrangement of parts the work is divided into stages, the nozzle velocity is reduced in each stage, and the energy of the steam is effectively given up to the rotating parts. This type admits of lower speeds than the other forms of turbines. Fig. 8. shows the arrangement of nozzles, buckets, and stationary blades or guiding vanes for two stages. Governing is accomplished by shutting off the steam from some of the nozzles. A complete Curtis turbine of the vertical type, direct connected to a 5,000 K.W. three-phase alternating-current generator, is shown in Fig. 9.

The advantages claimed for this turbine are:

1. High steam economy at all loads.
2. High steam economy with rapidly fluctuating loads.
3. Small floor space per K.W. capacity, reducing to a minimum the cost of real estate and buildings.
4. Uniform angular velocity.
5. Simplicity in operation and low expense for attendance.
6. Freedom from vibration.
7. Steam economy not appreciably impaired by wear or lack of adjustment in long service.
8. Adaptability to high steam pressure and high superheat without practical difficulty and with consequent improvement in economy.
9. Condensed water is kept entirely free from oil and can be returned to the boilers.

Many of these advantages apply equally well to the other types of turbines now on the market. All turbines are especially adapted to operation with superheated steam.

Engines should preferably be direct-connected as already stated, but this is not always feasible, and gearing, belt, or rope drives must be resorted to. Countershafts, belt or rope driven, arranged with pulleys and belts for the different generators, and with suitable clutches, are largely used in small stations. They consume considerable power and the bearings require attention.

Careful attention must be given to the lubrication of all running parts, and extensive oil systems are necessary in large plants.

In such systems a continuous circulation of oil over the bearings and through the engine cylinders is maintained by means of oil pumps. After passing through the bearings, the machine oil goes to a properly arranged oil-filter where it is cleaned and then pumped to the bearings again. A similar process is used in cylinder lubrication, the oil being collected from the exhaust steam and only enough new oil is added to make up for the slight amount lost. The latter system is not installed as frequently as the continuous system for bearings. In the Curtis turbine, vertical type, the oil is forced in between the two plates, forming the step bearing, at such a pressure that a thin film of oil is constantly maintained between these plates. It may be arranged so that if, for any reason, this pressure fails, the steam will be cut off from the

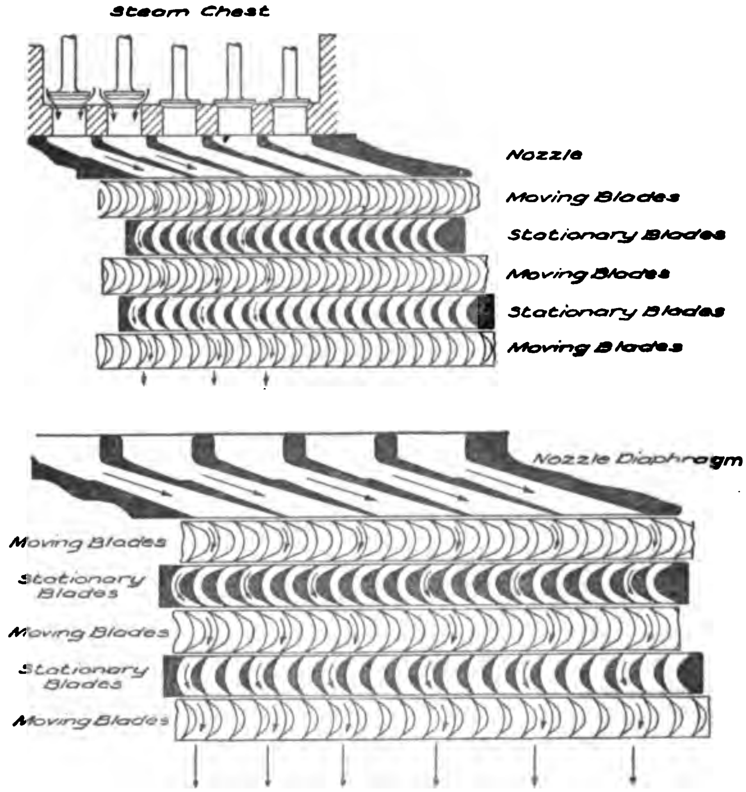


DIAGRAM OF NOZZLES AND BUCKETS IN CURTIS STEAM TURBINE.
Fig. 8.

turbine automatically. The bearings which support the shafts used with the generators at the Niagara Falls Power Companies' plants are generously flooded with oil and the turbines are arranged so as to remove a great deal of the weight of the rotating part from this bearing.

HYDRAULIC PLANTS.

Because of the relative ease with which electrical energy may be transmitted long distances, it has become quite common to locate large power stations where there is abundant water power, and to transmit the energy thus generated to localities where it is needed. This type of plant has been developed to the greatest extent in the western part of the United States, where in some cases the transmission lines are very extensive. The power houses now completed, or in the course of erection at Niagara Falls, are examples of the enormous size such stations may assume.

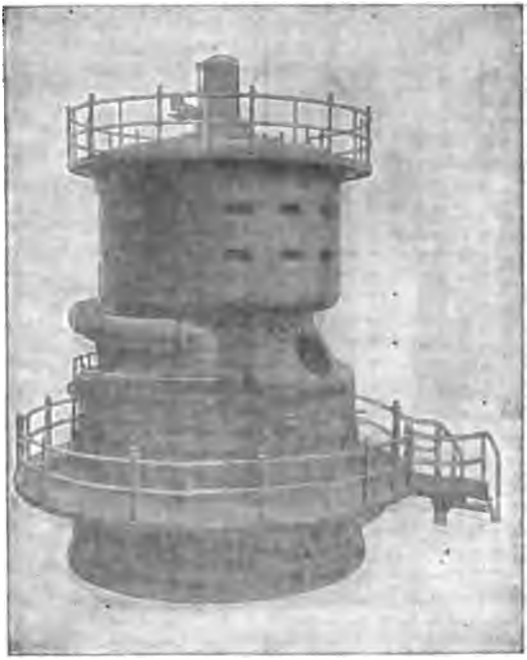


Fig. 9.

Before deciding to utilize water power for driving the machinery in central stations, the following points should be noted:

1. The amount of water power available.
2. The possible demand for power.
3. Cost of developing this power as compared with cost of plants using other sources of power.
4. Cost of operation compared with other plants and extent of transmission lines.

Hydraulic plants are often much more expensive than steam plants, but the first cost is more than made up by the saving in operating expenses.

Methods for the development of water powers vary with the nature and amount of the water supply, and they may be studied best by considering plants which are in successful operation, each one of which has been a special problem in itself. A full description of such plants would be too extensive to be incorporated here, but they can be found in the various technical journals.

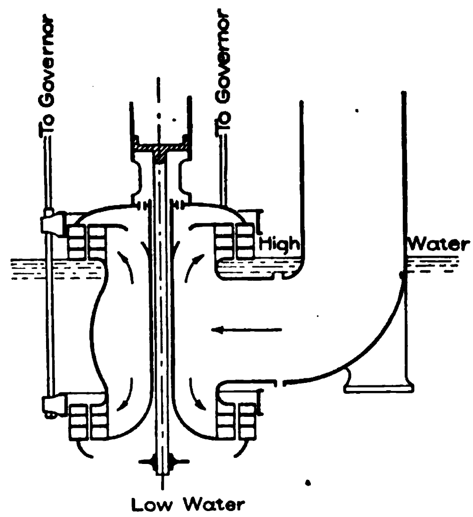
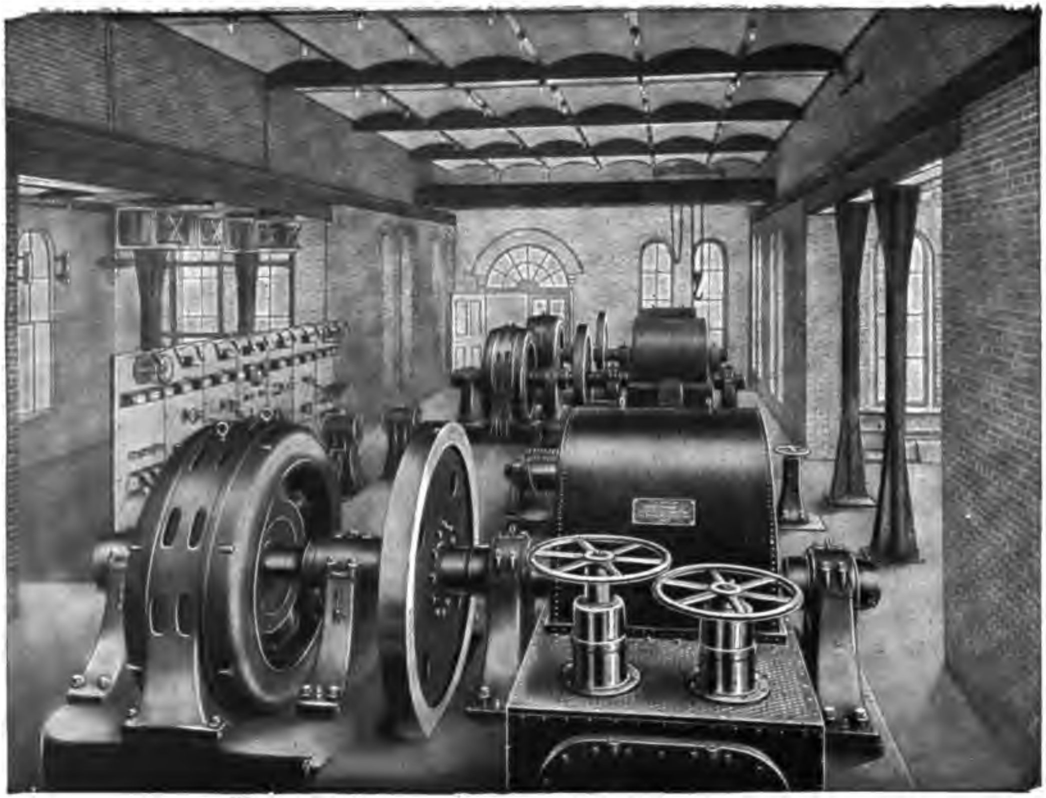


Fig. 10.

Water Turbines used for driving generators are of two general classes, reaction turbines and impulse turbines. The former may be subdivided into Parallel-flow, Outward-flow, and Inward-flow turbines. Parallel-flow turbines are suited for low falls, not exceeding 30 feet. Their efficiency is from 70 to 72%. Outward-flow and inward-flow turbines give an efficiency from 79 to 88%. Impulse turbines are suitable for very high falls and should be used from heads exceeding say 100 feet, though it is difficult to say at what head the reaction turbine would give place to the impulse wheel, as reaction turbines are giving good satisfaction on heads in the neighborhood of 200 feet, while impulse wheels are operated



INTERIOR OF PIKES PEAK POWER STATION.

The Pelton Water Wheel Company.

with falls of but 80 feet. The Pelton wheel is one of the best known types of impulse wheels. An efficiency as high as 86% is claimed for this type of wheel under favorable conditions. Fig. 10 shows a reaction wheel and Fig. 11 illustrates a Pelton wheel.

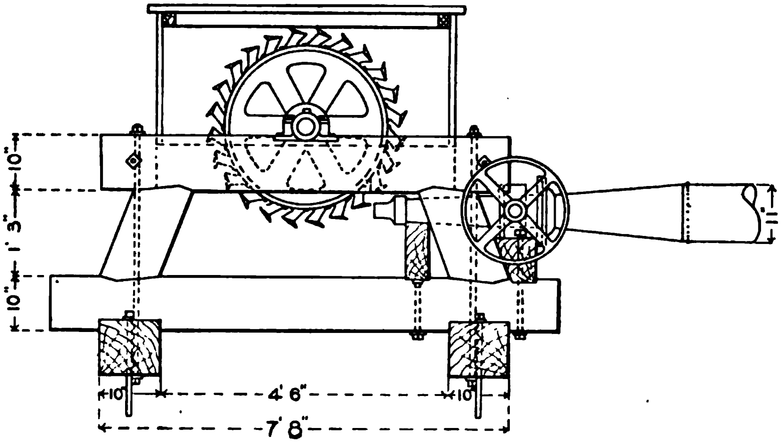


Fig. 11.

TABLE 7.
Pressure of Water.

Feet Head.	Pressure Pounds per Square Inch.	Feet Head.	Pressure Pounds per Square Inch.	Feet Head.	Pressure Pounds per Square Inch.	Feet Head.	Pressure Pounds per Square Inch.
10	4.33	105	45.48	200	86.63	295	127.78
15	6.49	110	47.64	205	88.80	300	129.95
20	8.66	115	49.81	210	90.96	310	134.28
25	10.82	120	51.98	215	93.13	320	138.62
30	12.99	125	54.15	220	95.30	330	142.95
35	15.16	130	56.31	225	97.46	340	147.28
40	17.32	135	58.48	230	99.63	350	151.61
45	19.49	140	60.64	235	101.79	360	155.94
50	21.65	145	62.81	240	103.90	370	160.27
55	23.82	150	64.97	245	106.13	380	164.61
60	25.99	155	67.14	250	108.29	390	168.94
65	28.15	160	69.31	255	110.46	400	173.27
70	30.32	165	71.47	260	112.62	500	216.58
75	32.48	170	73.64	265	114.79	600	259.90
80	34.65	175	75.80	270	116.96	700	303.22
85	36.82	180	77.97	275	119.12	800	346.54
90	38.98	185	80.14	280	121.29	900	389.86
95	41.15	190	82.30	285	123.45	1000	433.18
100	43.31	195	84.47	290	125.62		

The fore bay leading to the flume should be made of such size that the velocity of water does not exceed 1½ feet per second, and

TABLE 8.

Riveted Hydraulic Pipe.

Diam. of Pipe in inches.	Area of Pipe in sq. inches.	Thickness of Iron by wire gauge.	Head in Feet the Pipe will safely stand.	Cu. ft. Water Pipe will convey per min. at vel. 3 ft. per sec.	Weight per lineal ft. in lbs.
3	7	18	400	9	2
4	12	18	350	16	2¼
4	12	16	525	16	3
5	20	18	325	25	3½
5	20	16	500	25	4¼
5	20	14	675	25	5
6	28	18	296	36	4¼
6	28	16	487	36	5¾
6	28	14	743	36	7½
7	38	18	254	50	5¼
7	38	16	419	50	6¾
7	38	14	640	50	8½
8	50	16	367	63	7½
8	50	14	560	63	9½
8	50	12	854	63	13
9	63	16	327	80	8½
9	63	14	499	80	10¾
9	63	12	761	80	14¼
10	78	16	295	100	9¼
10	78	14	450	100	11¾
10	78	12	687	100	15¾
10	78	11	754	100	17½
10	78	10	900	100	19½
11	95	16	269	120	9¾
11	95	14	412	120	13
11	95	12	626	120	17¼
11	95	11	687	120	18¾
11	95	10	820	120	21
12	113	16	246	142	11¼
12	113	14	377	142	14
12	113	12	574	142	18½
12	113	11	630	142	19¾
12	113	10	753	142	22¾
13	132	16	228	170	12
13	132	14	348	170	15
13	132	12	530	170	20
13	132	11	583	170	22
13	132	10	696	170	24½
14	153	16	211	200	13
14	153	14	324	200	16
14	153	12	494	200	21½
14	153	11	543	200	23½
14	153	10	648	200	26
15	176	16	197	225	13¾
15	176	14	302	225	17
15	176	12	460	225	23
15	176	11	507	225	24½
15	176	10	606	225	28
16	201	16	185	255	14½
16	201	14	283	255	17¼
16	201	12	432	255	24¼
16	201	11	474	255	26½

Riveted Hydraulic Pipe. (Continued.)

Diam. of Pipe in inches.	Area of Pipe in sq. inches.	Thickness of Iron by wire gauge.	Head in Feet the Pipe will safely stand.	Cu. ft. Water Pipe will convey per min. at vel. 3 ft. per sec.	Weight per lineal ft. in lbs
16	201	10	567	255	29½
18	254	16	165	320	16½
18	254	14	252	320	20½
18	254	12	385	320	27¼
18	254	11	424	320	30
18	254	10	505	320	34
20	314	16	148	400	18
20	314	14	227	400	22½
20	314	12	346	400	30
20	314	11	380	400	32½
20	314	10	456	400	36½
22	380	16	135	480	20
22	380	14	206	480	24¾
22	380	12	316	480	32¾
22	380	11	347	480	35¾
22	380	10	415	480	40
24	452	14	188	570	27¼
24	452	12	290	570	35½
24	452	11	318	570	39
24	452	10	379	570	43½
24	452	8	466	570	53
26	530	14	175	670	29¼
26	530	12	267	670	38½
26	530	11	294	670	42
26	530	10	352	670	37
26	530	8	432	670	57¼
28	615	14	102	775	31¼
28	615	12	247	775	41¼
28	615	11	278	775	45
28	615	10	327	775	50¼
28	615	8	400	775	61¼
30	706	12	231	890	44
30	706	11	254	890	48
30	706	10	304	890	54
30	706	8	375	890	65
30	706	7	425	890	74
36	1017	11	141	1300	58
36	1017	10	155	1300	67
36	1017	8	192	1300	78
36	1017	7	210	1300	88
40	1256	10	141	1600	71
40	1256	8	174	1600	86
40	1256	7	189	1600	97
40	1256	6	213	1600	108
40	1256	4	250	1600	126
42	1385	10	135	1760	74½
42	1385	8	165	1760	91
42	1385	7	180	1760	102
42	1385	6	210	1760	114
42	1385	4	240	1760	133
42	1385	¼	270	1760	137
42	1385	3	300	1760	145
42	1385	5/16	321	1760	177
42	1385	⅜	363	1760	216

it should be free from abrupt turns. The same applies to the tail race. The velocity of water in wooden flumes should not exceed 7 to 8 feet per second. Riveted steel pipe is used for the penstocks and for carrying water from considerable distances under high heads. In some locations it is buried, in others it is simply placed on the ground. Wooden-stave pipe is used to a large extent when the heads do not much exceed 200 feet. Table 7 gives the pressure of water at different heads, while Table 8 gives considerable data relating to riveted-steel hydraulic pipe.

Governors are required to keep the speed constant under change of load and change of head. Various governors are manufactured which give excellent satisfaction.

TABLE 9.

Horse Power per cubic foot of water per minute for different heads.

Heads in Feet.	Horse Power.	Heads in Feet.	Horse Power	Heads in Feet.	Horse Power.	Heads in Feet.	Horse Power.
1	.0016098	170	.273666	330	.531234	490	.788802
20	.032196	180	.289764	340	.547332	500	.804900
30	.048294	190	.305862	350	.563430	520	.837096
40	.064392	200	.321960	360	.579528	540	.869292
50	.080490	210	.338058	370	.595626	560	.901488
60	.096588	220	.354156	380	.611724	580	.933684
70	.112686	230	.370254	390	.627822	600	.965880
80	.128784	240	.386352	400	.643920	650	1.046370
90	.144892	250	.402450	410	.660018	700	1.126860
100	.160980	260	.418548	420	.676116	750	1.207350
110	.177078	270	.434646	430	.692214	800	1.287840
120	.193176	280	.450744	440	.708312	900	1.448820
130	.209274	290	.466842	450	.724410	1000	1.609800
140	.225372	300	.482940	460	.740508	1100	1.770780
150	.241470	310	.499038	470	.756606		
160	.257568	320	.515136	480	.772704		

GAS ENGINES.

There are at present, in the United States, several successful electrical installations using gas engines as prime movers, while they have been operated abroad for a greater length of time. The advantages for gas engines are given as follows:

1. **Minimum fuel and heat consumption.**
2. **Light-load efficiency is higher than for the steam engines.**
3. **Low cost of operation and maintenance.**

4. Simplification of equipment and small number of auxiliaries.
5. No heat lost due to radiation when engines are idle.
6. Quick starting.
7. Extensions may be easily made.
8. High pressures are limited to the engine cylinders.

Fig. 12 shows the efficiency and amount of gas consumed by a 550 H.P. engine, Pittsburg natural gas being used.

The only auxiliaries needed are the igniter generators and the air compressors, with a pump for the jacket water in some cases. These may be driven by a motor or by a separate gas engine. The jacket water may be utilized for heating purposes in many plants. Cooling towers may be installed where water is scarce.

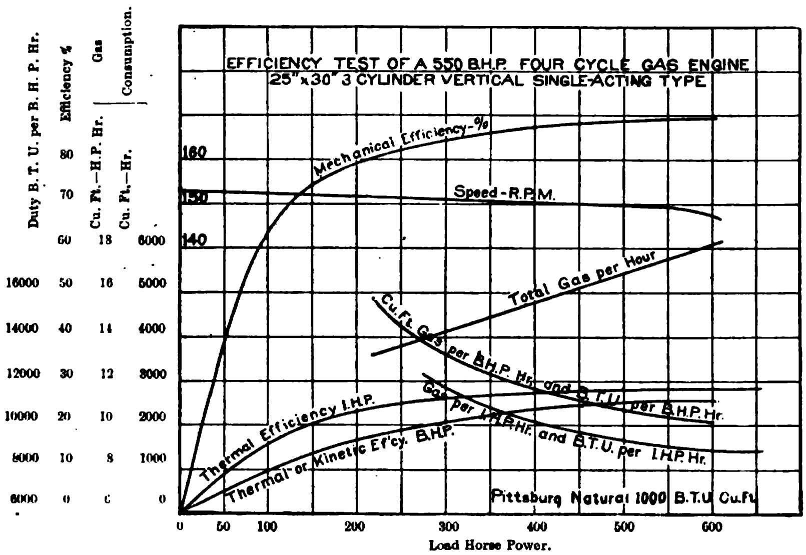


Fig. 12.

Parallel operation of alternators when direct-driven by gas engines has been successful, a spring coupling being used between the engines and generators in some cases to absorb the variation in angular velocity.

The fact that no losses occur, due to heat radiation when the machines are not running, and the lack of losses in piping, add greatly to the plant efficiency. If producer gas or blast furnace gas is used, a larger engine must be installed, to give the same power, than when natural or ordinary coal gas is used. Electric stations are often combined with gas works, and gas engines can be installed in such stations to particular advantage in many cases.

THE ELECTRICAL PLANT.

GENERATORS.

The first thing to be considered in the electrical plant is the generators, after which the auxiliary apparatus in the way of exciters, controlling switches, safety devices, etc., will be taken up. A general rule which, by the way, applies to almost all machinery for power stations is to select apparatus which is considered as "standard" by the manufacturing companies. This rule should be followed for two reasons. First, reliable companies employ men who may be considered as experts in the design of their machines, and their best designs are the ones which are standardized. Second, standard apparatus is from 15 to 25% cheaper than semi-standard or special work, owing to larger production, and it can be furnished on much shorter notice. Again, repair parts are more cheaply and readily obtained.

Specifications should call for performance, and details should be left, to a very large extent, to the manufacturers. Following are some of the matters which may be incorporated in the specifications for generators:

1. Type and general characteristics.
2. Capacity and overload with heating limits.
3. Commercial efficiency at various loads.
4. Excitation.
5. Speed and regulation.
6. Floor space.
7. Mechanical features.

As to the type of machine, this will be determined by the system selected. They may be direct-current, alternating-current, single or polyphase, or as in some plants now in operation, they may be double-current generators. The voltage, compounding, frequency, etc., should be stated. Direct-current machines are seldom wound for a voltage above 600, but alternating-current generators may be purchased which will give as high as 15,000 volts at the terminals. As a rule it is well not to use an extremely high voltage for the generators themselves, but to use step-up transformers in case a very high line voltage is necessary. Up to about 7,000 volts generators may be safely used directly on the line.

Above this local conditions will decide whether to connect the machine directly to the line or to step up the voltage. Machines wound for high potential are more expensive for the same capacity and efficiency, but the cost of step-up transformers and the losses in the same are saved by using such machines, so that there is a slight gain in efficiency which may be utilized in better regulation of the system, or in lighter construction of the line. On the other hand, lightning troubles are liable to be aggravated when transformers are not used, as the transformers act as additional protection to the machines, and if the transformers are injured they may be more readily repaired or replaced.

The following voltages are considered standard:

Direct-current generators 125, 250, 550–600.

Alternating-current systems, high pressure, 2,200, 6,000, 10,000, 15,000, 20,000, 30,000, 40,000, 60,000.

The generators, with transformers when used, should be capable of giving a no-load voltage 10% in excess of these figures. 25 and 60 cycles are considered as standard frequencies, the former being more desirable for railway work and the latter for lighting purposes.

The size of machines to be chosen has been briefly considered. Alternators are rated for non-inductive load or a power factor of unity. Aside from the overload capacity to be counted upon as reserve, the Standardization Report of the American Institute of Electrical Engineers recommends the following for the heating limits and overload capacity of generators:

Maximum values of temperature elevation,
Field and armature, by resistance, 50° C.
Commutator and collector rings and brushes, by thermometer, 55° C.
Bearings and other parts of machine, by thermometer, 40° C.

Overload capacity should be 25% for two hours, with a temperature rise not to exceed 15° above full load values, the machine to be at constant temperature reached under normal load, before the overload is applied. A momentary overload of 50% should be permissible without excessive sparking or injury. Some companies recommend an overload capacity of 50% for two hours when the machines are to be used for railway purposes.

As a rule, generators should have a high efficiency over a considerable range of load, although the nature of the load will have much to do with this. It is always desirable that maximum efficiency be as high as is compatible with economic investment.

Table 10 gives reasonable efficiencies which may be expected for generating apparatus. In order to arrive at what may be considered the best maximum efficiency to be chosen, the cost of power generation must be known, or estimated, and the fixed charges on capital invested must also be a known quantity. From the cost of power, the saving on each per cent increase in efficiency can be determined, and this should be compared with the charges on the additional investment necessary to secure this increased efficiency. A certain point will be found where the sum of the two will be a minimum.

If a generator is to be run for a considerable time at light loads, one with low "no-load" losses should be chosen. These losses are not rigidly fixed but they vary slightly with change of load. It is the same question of "all-day efficiency" which is treated, in the case of transformers, in "Power Transmission". Under no-load losses may be considered, in shunt-wound generators, friction losses, core losses, and shunt-field losses. I^2R losses in the series field, in the armature, and in the brushes, vary as the square of the load.

Table 10.

Average Maximum Efficiencies.

K.W.	Per Cent
5	85
10	88
25	90
50	92
150	93
200	94
500	95
1000	96

Dynamos, if for direct current, may be self-excited, shunt- or compound-wound, or separately excited. Separate excitation is not recommended for these machines. Alternators require separate excitation, though they may be compounded by using a portion of the armature current when rectified by a commutator. Automatic regulation of voltage is always desirable, hence the general use of compound-wound machines for direct currents. Many alternators using rectified currents in series fields for keeping the voltage nearly constant are in service in small plants as well as several of the so-called "compensated" alternators, arranged with special devices which maintain the same compounding with different power factors. The latter machine gives good satisfaction if properly cared for, but an automatic regulator, governed by the generator voltage and current, which acts directly on the exciter field, is taking its place. The capacity of the exciters must be such that they will furnish sufficient excitation to maintain normal voltage at the terminals of the generators when running at 50% overload. Table 11 gives the proper capacity of exciter for the generator listed.

TABLE 11.

Exciters for Single-Phase Alternating-Current Generators.

60 Cycles.

Alternator Classification.			Exciter Classification.		
Poles.	K.W.	Speed.	Poles.	K.W.	Speed.
8	60	900	2	1.5	1900
8	90	900	2	1.5	1900
8	120	900	2	1.5	1900
12	180	600	2	2.5	1900
16	300	450	2	4.5	1800

If direct-connected, the speeds of the generators will be determined by the prime mover selected. If belt-driven, small machines may be run at a high speed, as high-speed machines are cheaper than slow- or moderate-speed generators. In large sizes, this saving is not so great.

When shunt-wound dynamos are used, the inherent regulation should not exceed 2 to 3% for large machines. For alternators, this is much greater and depends on the power factor of the load. A fair value for the regulation of alternators on non-inductive load is 10 per cent.

Exciters may be either direct-connected or belted to the shaft of the machine which they excite, or they may be separately driven. They are usually compound-wound and furnish current at 125 or 250 volts. Separately driven exciters are preferred for most plants as they furnish a more flexible system, and any drop in the speed of the generator does not affect the exciter voltage. Ample reserve capacity of exciters should be installed, and in some cases storage batteries, used in conjunction with exciters, are recommended in order to insure reliability of service.

Motor-generator sets, boosters, frequency changers, and other rotating devices come under the head of special apparatus and are governed by the same general rules as generators.

Transformers for stepping the voltage from that generated by the machine up to the desired line voltage, or *vice versa*, at the substation, may be of three general types, according to the method of cooling. Large transformers require artificial means of cooling, if they are not to be too bulky and expensive. They may be air-cooled, oil-cooled, or water-cooled.

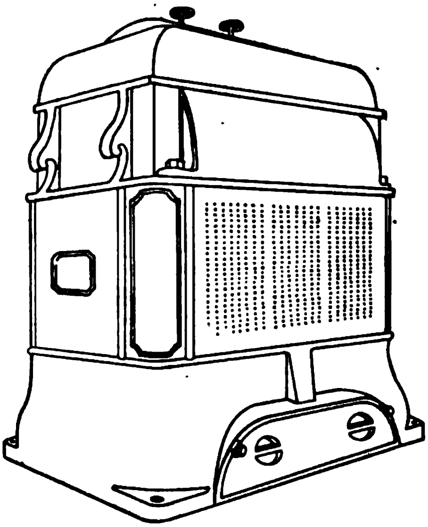


Fig. 13.

Air-cooled transformers are usually mounted over an air-tight pit fitted with one or more motor-driven blowers which feed into the pit. The transformer coils are subdivided so that no part of the winding is at a great distance from air and the iron is provided with ducts. Separate dampers control the amount of air which passes between the coils or through the iron. Such transformers give good satisfaction for voltages up to 20,000 or higher, and can be built for any capacity. Care must be taken to see that there is no liability of the air supply failing, as the capacity of the transformers is greatly reduced when not supplied with air. Fig. 13 shows a three-phase air-blast transformer.

Oil-cooled transformers have their cores and windings placed in a large tank filled with oil. The oil serves to conduct the heat to the case, and the case is usually either made of corrugated sheet metal or of cast iron containing deep grooves, so as to increase the radiating surface. These transformers do not require such heavy insulation on the outside of the coils as air-blast machines because the oil serves this purpose. Simple oil-cooled transformers are seldom built for capacities exceeding 250 K.W. as they become too bulky, but they are employed for the highest voltages now in use. Fig. 14 shows a transformer of this type.

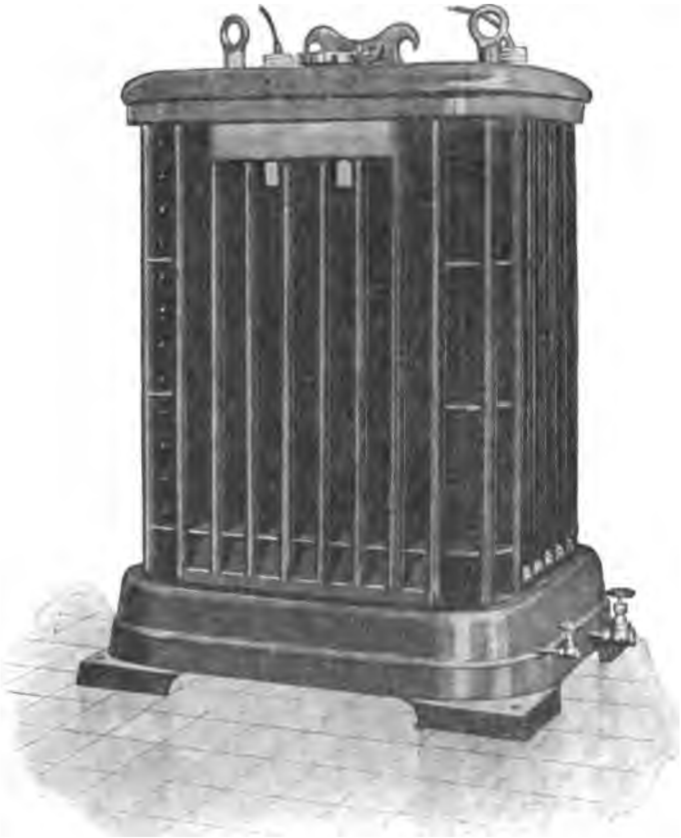


Fig. 14. 150 K.W. Self-Cooled Oil Transformer.

Water-cooled transformers. When large transformers for high voltages are required, the water-cooled type is usually selected. This type is similar to an oil-cooled transformer, but with water tubes arranged in coils in the top. Cold water passes through these tubes and aids in removing heat from the oil. Some types have the low-tension windings made up of tubes through which the water circulates. Water-cooled transformers must not have

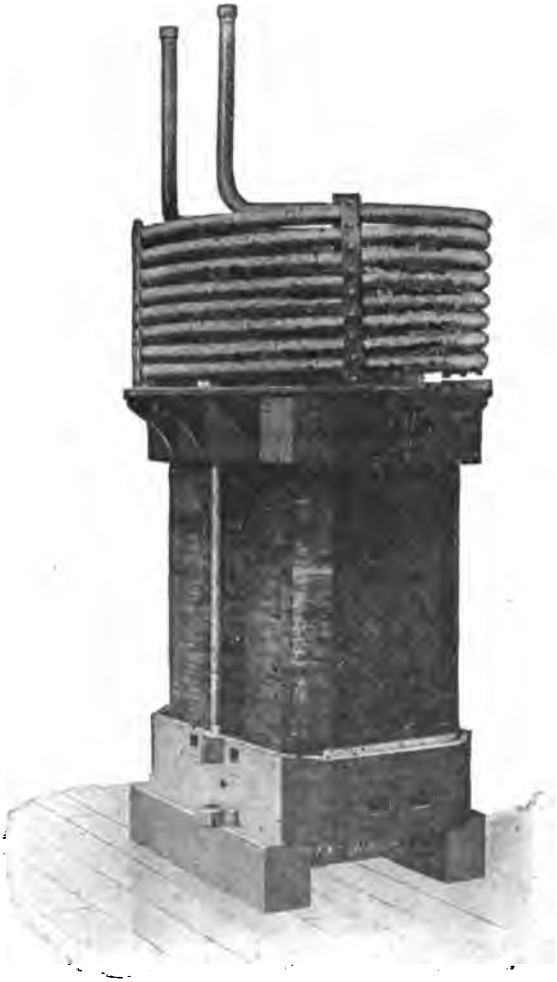


Fig. 15. Water-Cooled Transformer.

the supply of cooling water shut off for any length of time when under normal load or they will overheat. Fig. 15 shows a water-cooled transformer.

For connections of transformers, see "Power Transmission".

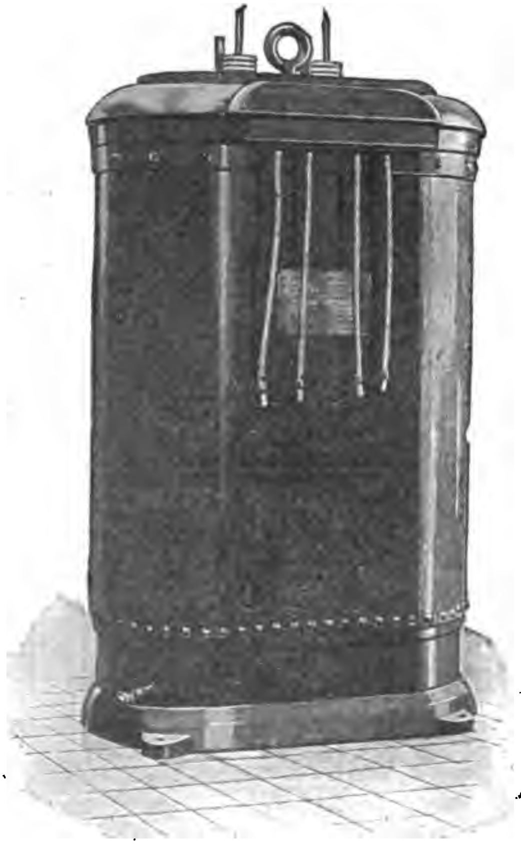
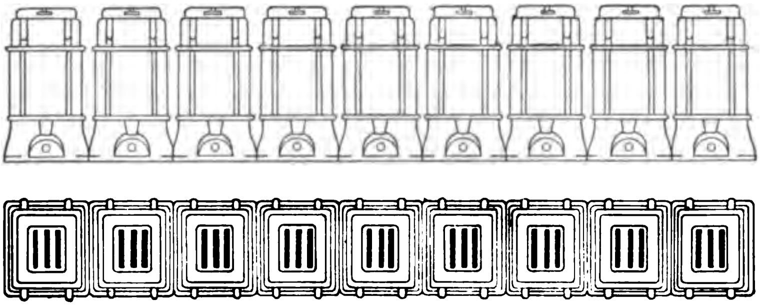


Fig. 15. 400 K.W. Water Cooled Oil Transformer.

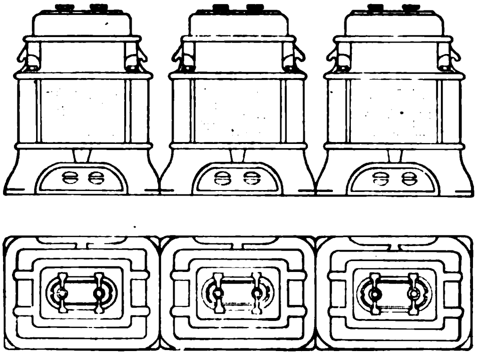
One or more spare transformers should always be on hand and they should be arranged so that they can be put into service on very short notice.

Three-phase transformers allow a considerable saving in floor space, as can be seen by referring to Fig. 16; they are cheaper than three separate transformers which make up the same capacity, but they are not as flexible as a single-phase transformer and one complete unit must be held for a reserve or "spare" transformer.

Storage Batteries. The use of storage batteries for central stations and substations is clearly outlined in "Storage Batteries". The chief points of advantage may be enumerated as follows:



Single-Phase Air-Blast Transformers. Total Capacity 3,000 K.W.



Three-Phase Air-Blast Transformers. Total Capacity 3,000 K.W.

Fig. 16.

1. Reduction in fuel consumption due to the generating machinery being run at its greatest economy.
2. Better voltage regulation.
3. Increased reserve capacity and less liability to interruption of service.

The main disadvantage is the high cost.

Switchboards. The switchboard is the most vital part of the whole system of supply, and should receive consideration as such. Its objects are: to collect the energy as supplied by the generators and direct it to the desired feeders, either overhead or under ground; furnish a support for the various measuring instruments connected in service, as well as the safety devices for the protection of the generating apparatus; and control the pressure of the supply. Some of the essential features of all switchboards are:

1. The apparatus and supports must be fire-proof.
2. The conducting parts must not overheat.
3. Parts must be easily accessible.
4. Live parts except for low potentials must not be placed on the front of the operating panels.
5. The arrangement of circuits must be symmetrical and as simple as it is convenient to make them.
6. Apparatus must be arranged so that it is impossible to make a wrong connection that would lead to serious results.
7. It should be arranged so that extensions may be readily made.

There are two general types—in the first, all of the switching and indicating apparatus is mounted directly on panels, and in the second, the current-carrying parts are at some distance from the panels, the switches being controlled by long connecting rods; operated electrically or by means of compressed air. The first may again be divided into direct-current and alternating-current switchboards. It is from the first class of apparatus that the switchboard gets its name and the term is still applied, even when the board proper forms the smallest part of the equipment. Switchboards have been standardized to the extent that standard generator, exciter, feeder, and motor panels may be purchased for certain classes of work, but the vast majority of them are made up as semi-standard or special.

The leads which carry the current from the machines to the switches should be put in with very careful consideration. Their size should be such that they will not heat excessively when carrying the rated overload of the machine, and they should preferably be placed in fire-proof ducts, although low-potential leads do not always require this construction. Curves showing sizes for lead-covered cables for different currents are given in "Power Transmission". Table 12 gives standard sizes of wires and cables together with the thickness of insulation necessary for different voltages. Cables should be kept separate as far as possible so that if a fault does occur on one cable, neighboring conductors will not be injured. For lamp and instrument wiring, such as leads to potential and current transformers, the following sizes of wire are recommended:

No. 16 or No. 14, wiring to lamp sockets.

No. 12 wire, $\frac{3}{64}$" rubber insulation, all other small wiring under 600 volts potential.

No. 12, $\frac{3}{32}$" rubber insulation for primaries of potential transformers from 600 to 3,500 volts.

No. 8, $\frac{5}{32}$" rubber insulation for primaries of potential transformers up to 6,600 volts.

No. 8, $\frac{7}{32}$ rubber insulation for primaries of potential transformers up to 10,000 volts.

No. 4, $\frac{9}{32}$ rubber insulation for primaries of potential transformers up to 15,000 volts.

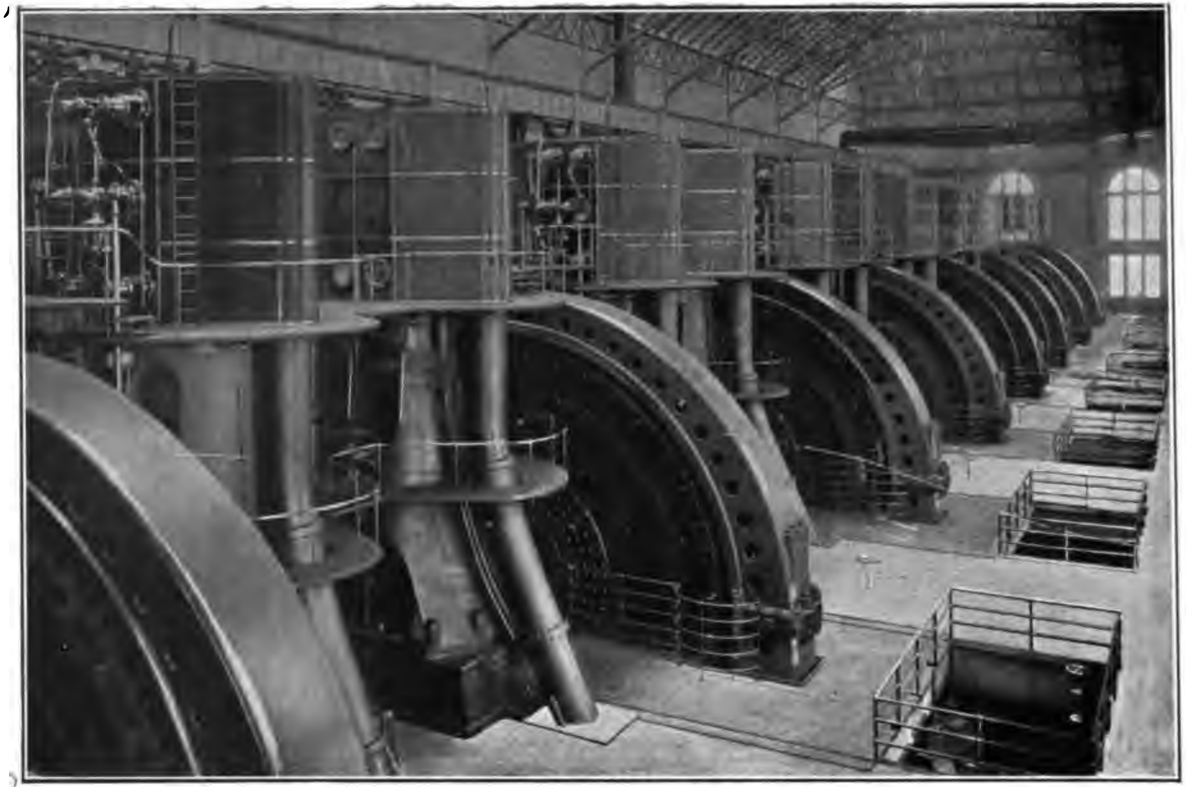
No. 4, $\frac{11}{32}$ rubber insulation for primaries of potential transformers up to 20,000 volts.

No. 4, $\frac{13}{32}$ rubber insulation for primaries of potential transformers up to 25,000 volts.

Where high-tension cables leave their metallic shields they are liable to puncture, so that the sheath should be flared out at this point and the insulation increased by the addition of compound. Fig. 17 shows such cable bells, as they are called, as recommended by the General Electric Company.

Central-station switchboards are usually constructed of panels about 90 inches high, from 16 inches to 36 inches wide, and 1½ inches to 2 inches thick. Such panels are made of Blue Vermont, Pink Tennessee, or White Italian marble, or of black enameled slate. Slate is not recommended for voltages exceeding 1,100. The panels are in two parts, the sub-base being from 24 to 28 inches high. They are polished on the front and the edges are beveled. Angle and tee bars, together with foot irons and tie rods, form the supports for such panels, and on these panels are mounted the instruments, main switches, or controlling apparatus for the main switches, as the case may be, together with relays and hand wheels for rheostats and regulators. Small panels are sometimes mounted on pipe supports.

The usual arrangement of the panels is to have a separate panel for each generator, exciter, and feeder, together with what is known as a station or total-output panel. In order to facilitate extensions and simplify connections, the feeder panels are located



EIGHT 5,000-K. W. GENERATORS, INSTALLED AT THE MANHATTAN STATION, NEW YORK CITY

Westinghouse Electric & Mfg. Co.

at one end of the board and the generator panels are placed at the other end, and the total-output panel between the two. The main bus bars extend throughout the length of the generator and feeder panels, and the desired connections are readily made. The instruments required are very numerous and a brief description only of a few of the more important can be given here.

TABLE 12.

Standard Wire and Cable.

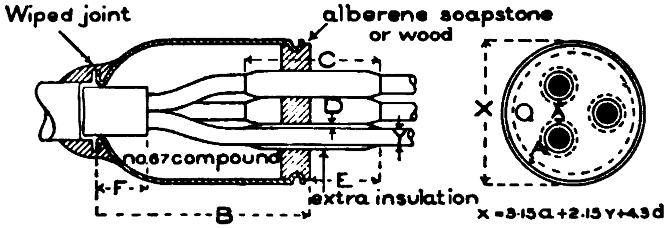
Wire (Solid).

Area.	Diam. Inches.	Terminal Drillings.	Amps.	Thickness of Rubber Insulation.							Gauge.
Circular Mils.	Bare.		Con. Current Capacity.	Volts 600	3500	6600	10000	15000	20000	25000	B. & S
				Special Insulation.							
2,582	.051	No. 30 Dr.	4								16
4,106	.064	30 "	6	$\frac{3}{64}$							14
6,530	.081	30 "	10	$\frac{3}{64}$	$\frac{3}{32}$						12
16,510	.128	18 "	25	$\frac{3}{64}$	$\frac{3}{32}$	$\frac{5}{32}$	$\frac{7}{32}$				8
26,251	.162	5 "	40	$\frac{1}{16}$							6
41,743	.204	$\frac{1}{4}$ "	60	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{5}{32}$	$\frac{7}{32}$	$\frac{21}{64}$	$\frac{14}{32}$	$\frac{17}{32}$	4
66,373	.257	$\frac{5}{16}$ "	90	$\frac{1}{16}$							2
83,695	.289	$\frac{11}{32}$ "	110	$\frac{5}{64}$							1
105,593	.325	$\frac{3}{8}$ "	130	$\frac{5}{64}$	$\frac{3}{32}$	$\frac{5}{32}$	$\frac{7}{32}$	$\frac{21}{64}$	$\frac{14}{32}$	$\frac{17}{32}$	0
133,079	.365	$\frac{7}{16}$ "	170	$\frac{5}{64}$							00
167,805	.410	$\frac{15}{32}$ "	205	$\frac{5}{64}$							000
211,600	.460	$\frac{17}{32}$ "	250	$\frac{5}{64}$	$\frac{3}{32}$	$\frac{5}{32}$	$\frac{7}{32}$	$\frac{21}{64}$	$\frac{14}{32}$	$\frac{17}{32}$	0000

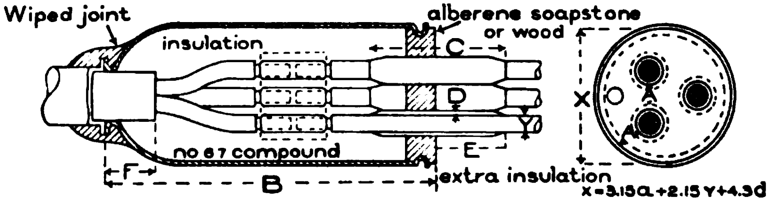
Cable.

(Stranded.)

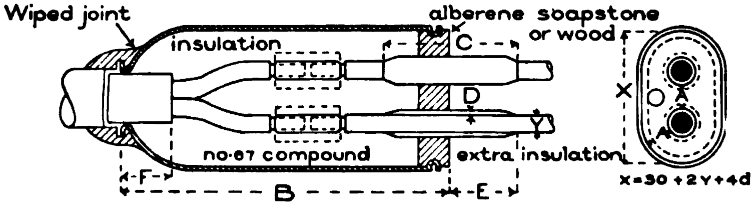
Circular Mils.	Diameter. Inches Bare.	Terminal Drilling	Con. Curr. Capacity. Amps.	Thickness of Rubber Insulation. (For 6000 V. only.)
250,000	.568	$\frac{5}{8}$'	290	$\frac{3}{32}$
300,000	.637	$\frac{23}{32}$"	340	$\frac{3}{32}$
350,000	.680	$\frac{3}{4}$"	380	$\frac{3}{32}$
400,000	.735	$\frac{13}{16}$"	420	$\frac{3}{32}$
500,000	.820	$\frac{29}{32}$"	500	$\frac{3}{32}$
600,000	.900	1"	575	$\frac{7}{64}$
800,000	1.037	1$\frac{1}{8}$"	710	$\frac{7}{64}$
1,000,000	1.157	1$\frac{1}{4}$"	830	$\frac{7}{64}$
1,500,000	1.412	1$\frac{1}{2}$"	1100	$\frac{1}{8}$
2.000,000	1.65	1$\frac{3}{4}$"	1350	$\frac{1}{8}$



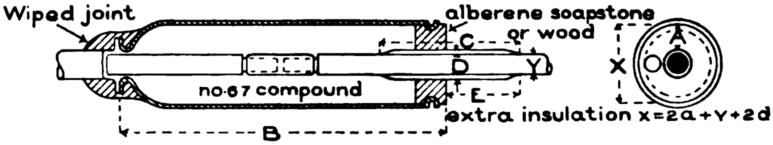
Three-Conductor Cable Without Joints.



Three-Conductor Cable With Joints.



Two-Conductor Cable With Joints.



Single-Conductor Cable With Joints.

VOLTS.	A	B	C	D	E	F
6600	1	12	5	⅛	2½	1
13200	1½	15	8	¼	4	2
26400	2	19	14	½	7	4

⅛-inch Lead or 1/16-inch Brass Bells.

Fig. 17.

For direct current generator panels there are usually required:

1 Main switch
1 Field switch.
1 Ammeter.
1 Voltmeter.
1 Field rheostat with controlling mechanism.
1 Circuit breaker
Bus bars and various connections.

These may be arranged in any suitable order, the circuit breaker being preferably located at the top so that any arcing which may occur will not injure other instruments. Fig. 18 gives a wiring diagram of such a panel.

The main switch may be single or double throw, depending on whether one or two sets of bus bars are used. It may be triple pole as shown in Fig. 18, in which the middle bar serves as the equalizing switch, or the equalizing switch may be mounted on a pedestal near the machine, in which case the generator switch would be double-pole.

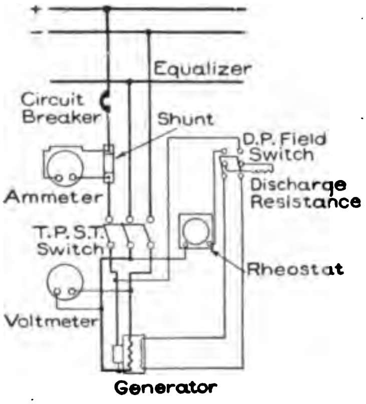


Fig. 18.

The field switch for large machines should be double-pole fitted with carbon breaks and arranged with a discharge resistance consisting of a resistance which is thrown across the terminals of the field just before the main circuit is opened. One voltmeter located on a swinging bracket at the end of the panel, and arranged so that it can be thrown across any machine or across the bus bars by means of a dial switch, is sometimes used, but it is preferable to have a separate meter for each generator.

Small rheostats are mounted on the back of the panel, but large ones are chain operated and preferably located below the floor, the controlling hand wheel being mounted on the panel.

The circuit breaker may be of the carbon break or the magnetic blow-out type. Fig. 19 shows circuit breakers of both types. Lighting panels for low potentials are often fitted with fuses instead of circuit breakers, in which case they may be open fuses on the back of the panel or enclosed fuses on either the front or back of the panel.

Direct-Current feeder panels contain:

1 Ammeter.
1 Circuit Breaker.
1 or more main switches, single-pole, and single- or double-throw.
1 recording wattmeter, not always used
Apparatus for controlling regulators when such are used.

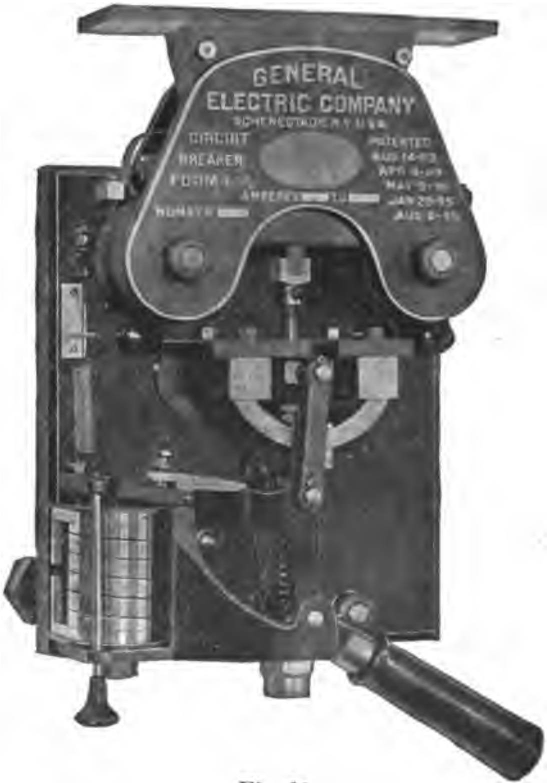


Fig. 19.

One voltmeter usually serves for several feeder panels, such a meter being mounted above the panels or on a swinging bracket at the end. Switches should preferably be of the quick-break type. Fig. 20 shows some standard railway feeder panels.

Exciter Panels are nothing more than generator panels on a small scale.

Total Output Panels contain instruments recording the total power delivered by the plant to the switchboard. Alternating-current panels for potentials up to 1,100 volts follow the same general construction. Synchronizing devices are necessary on the generator panels, and additional ammeters are used for polyphase boards. Sometimes the exciter and generator panels are combined in one. Fig. 21 shows such a combination. The same construction is sometimes used for voltages up to 2,500, though it is not usually recommended. The paralleling of alternators is treated in "Management of Dynamo Electric Machinery".

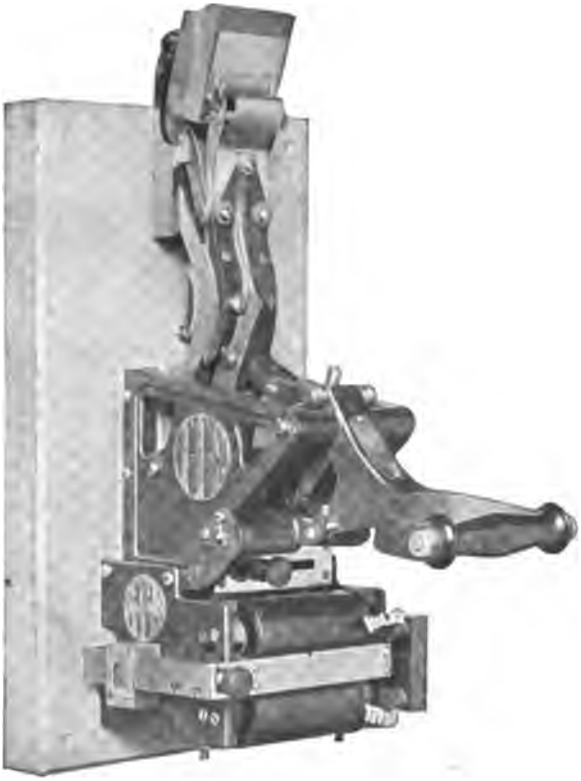


Fig. 19.

For the higher voltages, the measuring instruments are no longer connected directly in the circuit, and the main switch is not mounted directly on the panel. Current and potential transformers are used for connecting to the indicating voltmeters and ammeters, and the recording wattmeters and potential transformers are used for the synchronizing device. These transformers are mounted at some distance from the panel, while the switches may

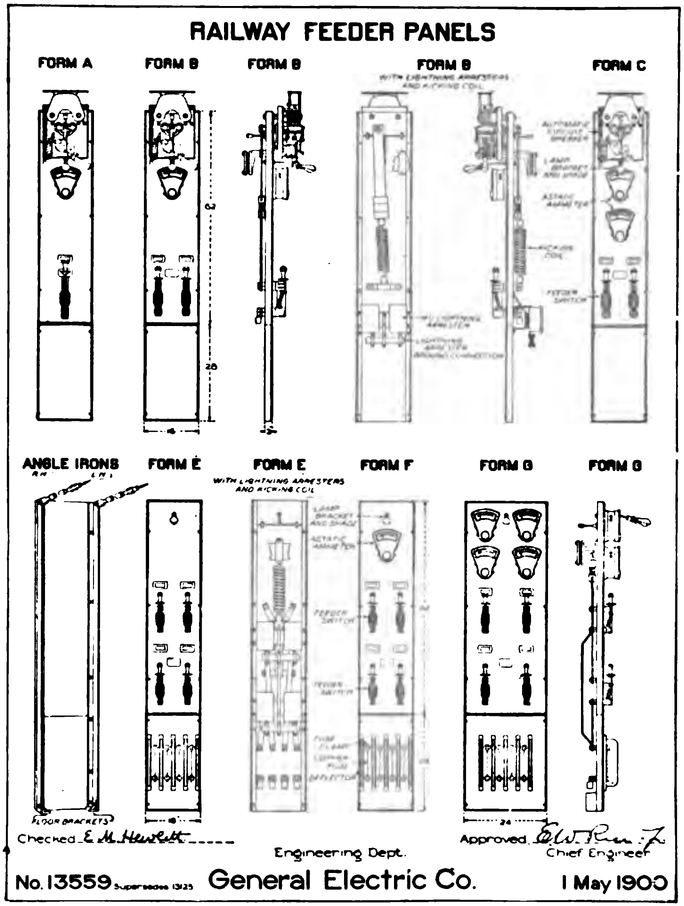
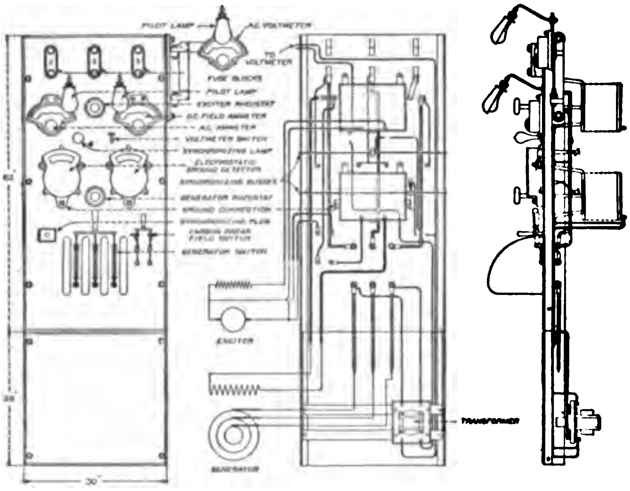


Fig. 20.

be located near the panel and operated by a system of levers, or they may be located at considerable distance and operated by electricity or by compressed air.

Oil Switches are recommended for all high potential work for the following reasons: By their use it is possible to open circuits of higher potential and carrying greater currents than with any other type of switch. They may be made quite compact. They may readily be made automatic and thus serve as circuit breakers for the protection of machines and circuits when overloaded.

SWITCHBOARD PANEL FOR
ONE THREE-PHASE ALTERNATING CURRENT GENERATOR
TO 2500 VOLTS



CLASSIFICATION

Type	Volts	Amperes	Form	Switch	Field Ammeter	Synchronizing Device
A T G	2500	130	A 1	S T	with	with
A T G	2500	130	A 2	S T	with	without
A T G	2500	130	A 3	S T	without	with
A T G	2500	130	A 4	S T	without	without
A T G	2500	130	A 5	D T	with	without
A T G	2500	130	A 6	D.T.	without	without

Transformer is calibrated with Voltmeter only. Therefore Synchronizing Plug must be removed for correct Voltmeter reading

Fig. 21.

There are several types on the market. One constructed for three-phase work, to be closed by hand and to be electrically tripped or opened by hand, is shown in Fig. 22. This shows the switch without the can containing the oil. Fig. 23 shows a similar switch hand-operated, with the can in place. Both of these switches are arranged to be mounted on the panel. Fig. 24 shows how the same switches are mounted when placed at some distance from the panel. For high voltages, they are placed in brick cells and often three separate single-pole switches are used, each placed in a separate cell so that injury to the contacts in one leg will in no way affect the other parts of the switch. A form of oil switch used for the very highest potentials and currents met with in practice, is shown in Fig. 25. This particular switch is operated by means of an electric motor, though it may be as readily arranged to operate by means of a solenoid or by compressed air. General practice is to place all high-tension bus bars and circuits in separate compartments formed by brick or cement, and duplicate bus bars are quite common.

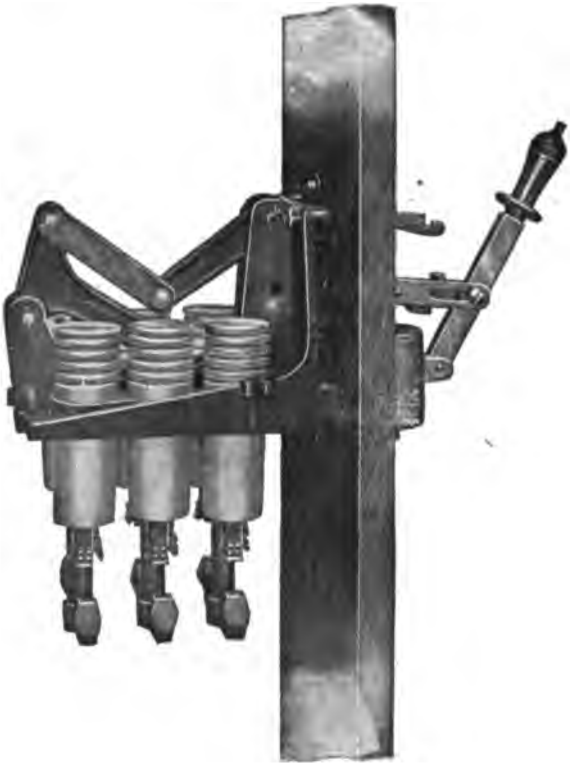
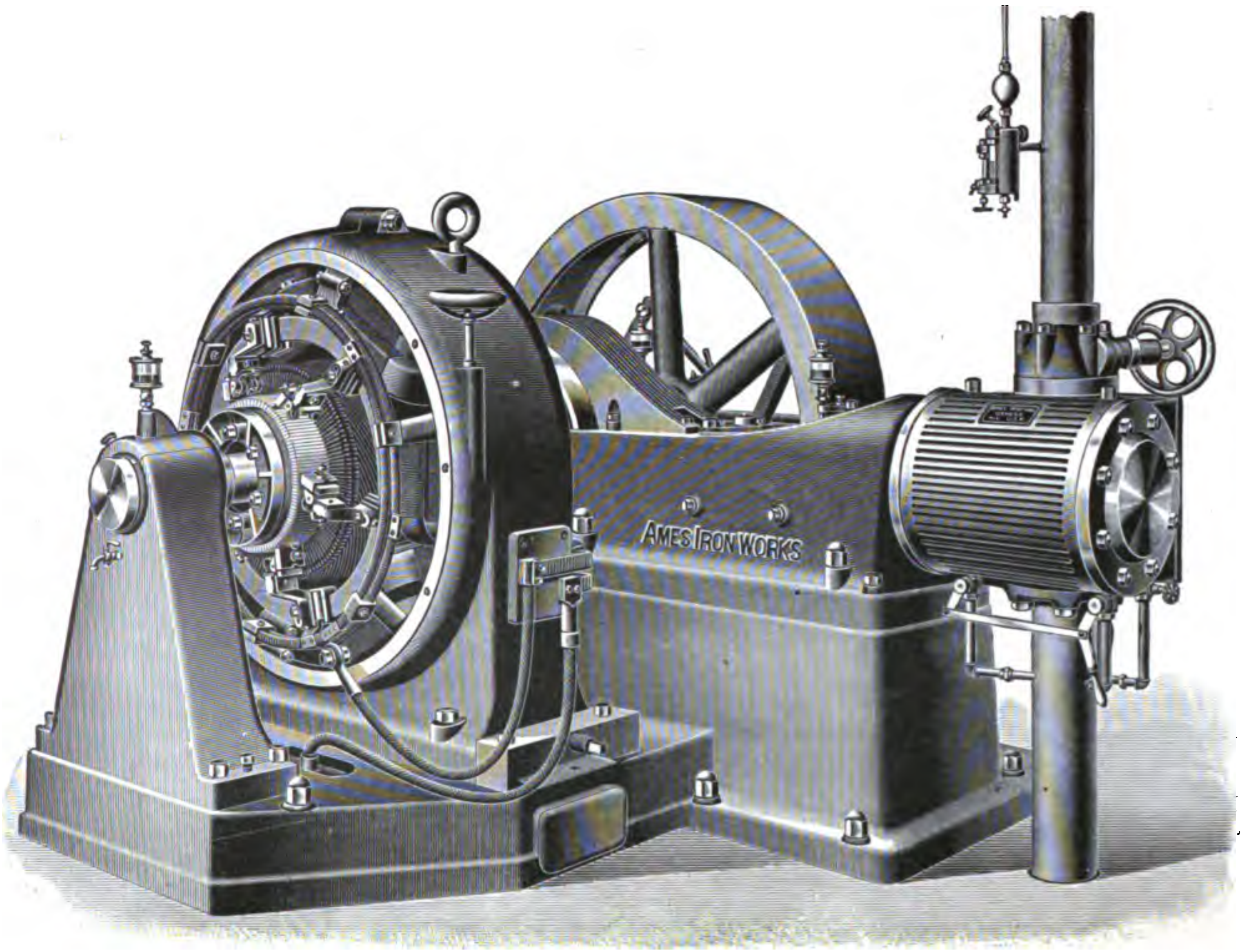


Fig. 22.

Oil switches are made automatic by means of tripping magnets, which are connected in the secondary circuits of current transformers, or they may be operated by means of relays fed from the secondaries of current transformers in the main leads. Such relays are made very compact and can be mounted on the



ENGINE DIRECT-CONNECTED WITH WESTINGHOUSE GENERATOR.
Ames Iron Works

front or back of the switchboard panels. The wiring of such tripping devices is shown in Fig. 26.

With remote control of switches, the switchboard becomes in many instances more properly a switch house, a separate building being devoted to the bus bars, switches, and connections. In other cases a framework of angle bars or gas pipe is made for the support of the switches, bus bars, current and potential transformers, etc.

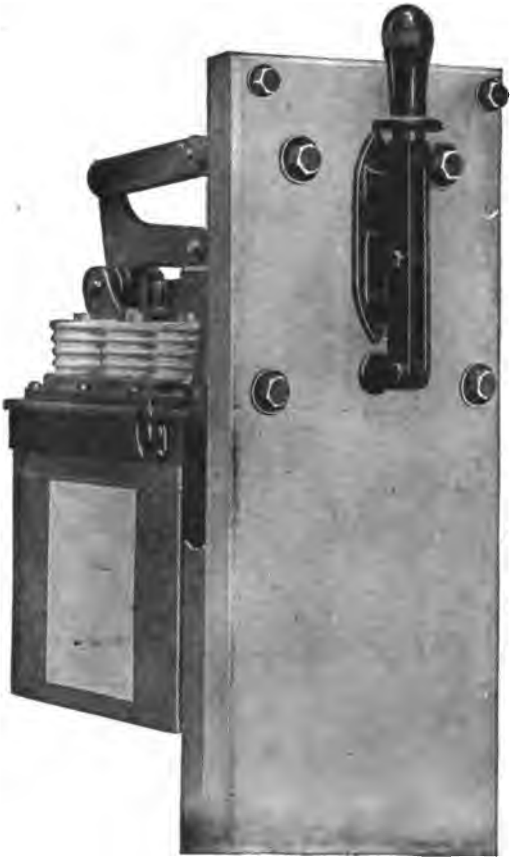
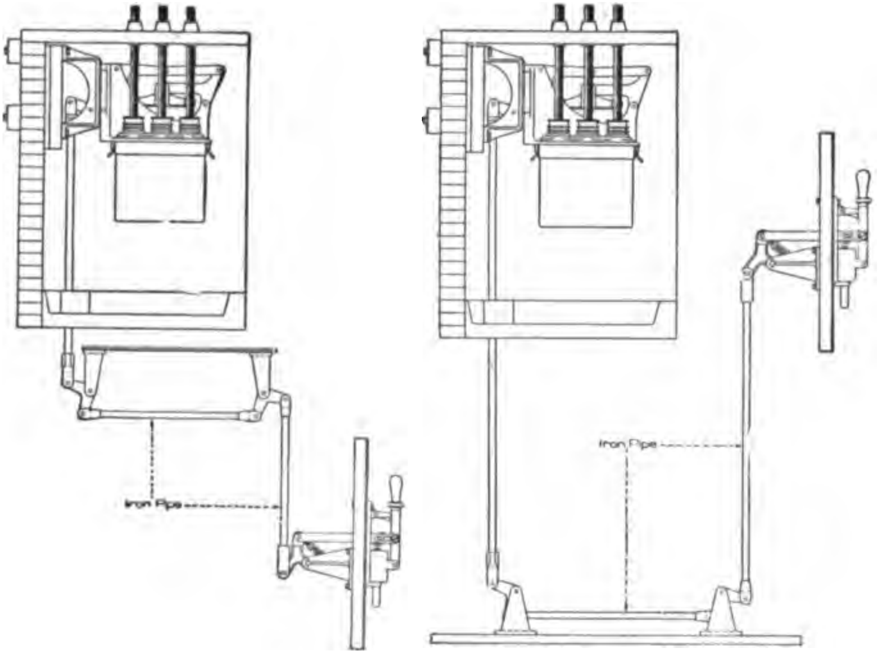


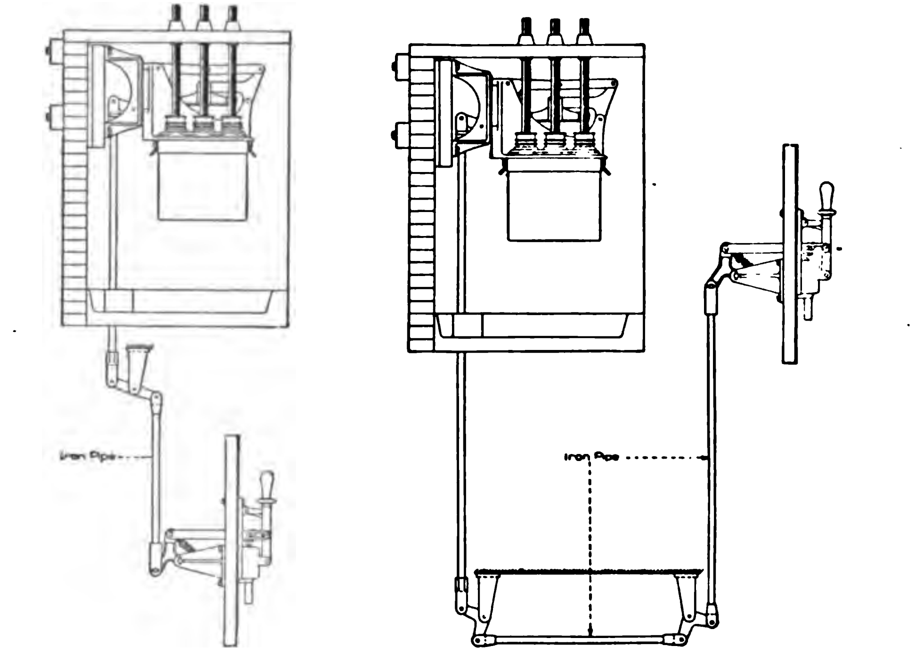
Fig. 23.

Additional types of panels which may be mentioned are transformer panels, usually containing switching apparatus only; rotary converter panels for both the alternating current and direct-current sides; induction-motor panels and arc-board panels. The latter.



Form K Oil Switches Located Above and Back of Operating Panel.

Form K Oil Switches Located Below and Back of Operating Panel.



Form K Oil Switches Located Above Operating Panel.

Form K Oil Switches Located Back of Operating Panel.

Fig. 24.

are arranged to operate with plug switches. A single panel used in the operation of series transformers on arc-lighting circuits is shown in Fig. 27.

Safety Devices. In addition to the ordinary overload tripping devices which have already been considered, there are various safety devices necessary in connection with the operation of central stations. One of the most important of these is the *lightning arrester*. For direct-current work, the lightning arrester takes the form of a single gap connected in series with a high resistance and fitted with some device for destroying the arc formed by discharge to the ground. One of these is connected between either side of the circuit and the ground, as shown diagrammatically in Fig. 28. A "kicking" coil is connected in circuit between the arresters and the machine to be protected, to aid in forcing the lightning discharge across the gap. In railway feeder panels such kicking coils are mounted on the backs of the panels.

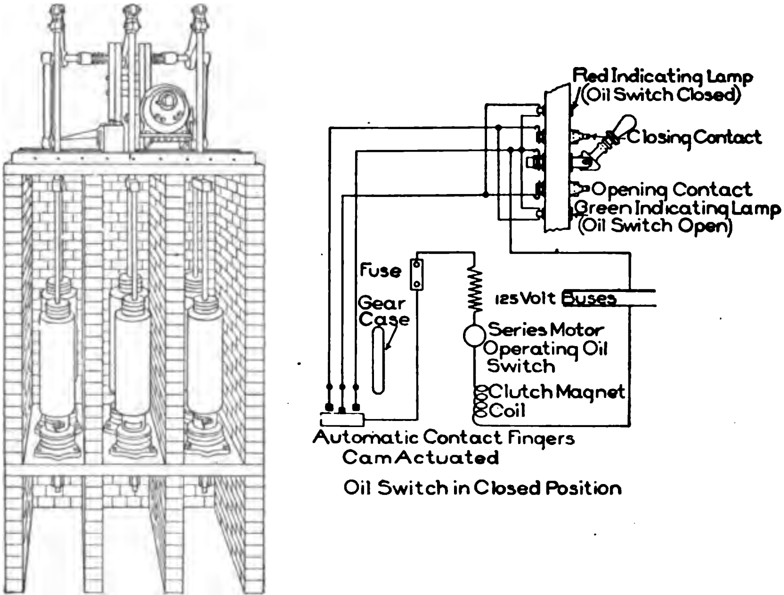


Fig. 25.

For alternating-current work, several gaps are arranged in series, these gaps being formed between cylinders of "non-arcing" metal. High resistances and reactance coils are used with these,

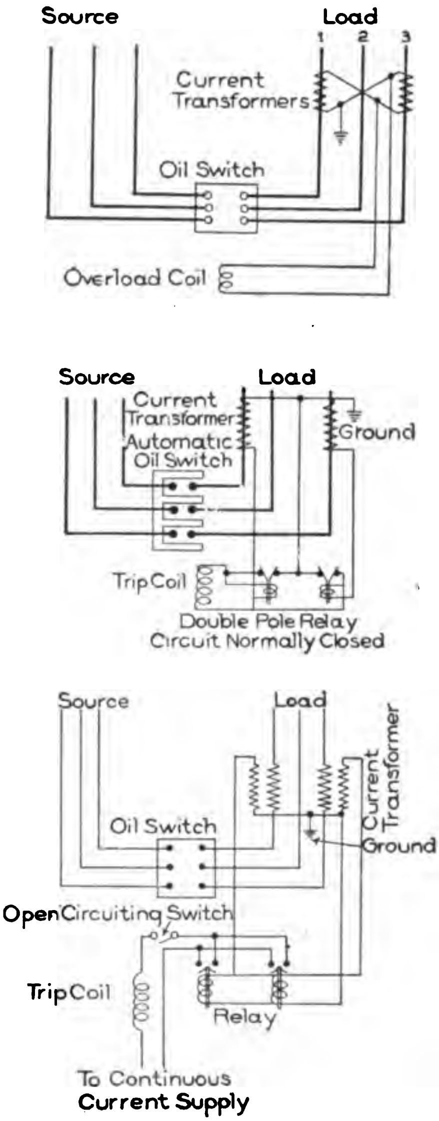


Fig. 26.

as in direct-current arresters. Fig. 29 shows connections for a 10,000-volt lightning arrester. Lighting arresters should always be provided with knife blade switches so that they can be disconnected from the circuit for inspection and repairs. A typical installation of lightning arresters is shown in Fig. 30.

Reverse-current relays are installed when machines or lines are operated in parallel. If two or more alternators are running and connected to the same set of bus bars, and one of these should fail to generate voltage by the opening of the field circuit, or some other cause, the other machine would feed into this generator and might cause considerable damage before the current flowing would be sufficient to operate the circuit breaker by means of the overload trip coils. To avoid this, reverse-current relays are used. They are so arranged as to operate at say ¼ the normal current of the machine or line, but to operate only when the power is being delivered in the wrong direction.

Speed-limit devices are used on both engines and rotary converters to prevent racing in the one case and running away in the second. Such devices act on the steam supply of engines and on the direct-current circuit breakers of rotary converters, respectively.

Complete wiring diagram for a railway switchboard is shown in Fig. 31.

Substations. Substations are for the purpose of transforming the high potentials down to such potentials as can be used on motors or lamps, and in many cases to convert alternating current into direct current. Step-down transformers do not differ in any respect from step-up transformers. Either motor-generator sets or rotary converters may be used to change from alternating to direct current. The former consist of synchronous or induction motors, direct connected to direct-current generators, mounted on

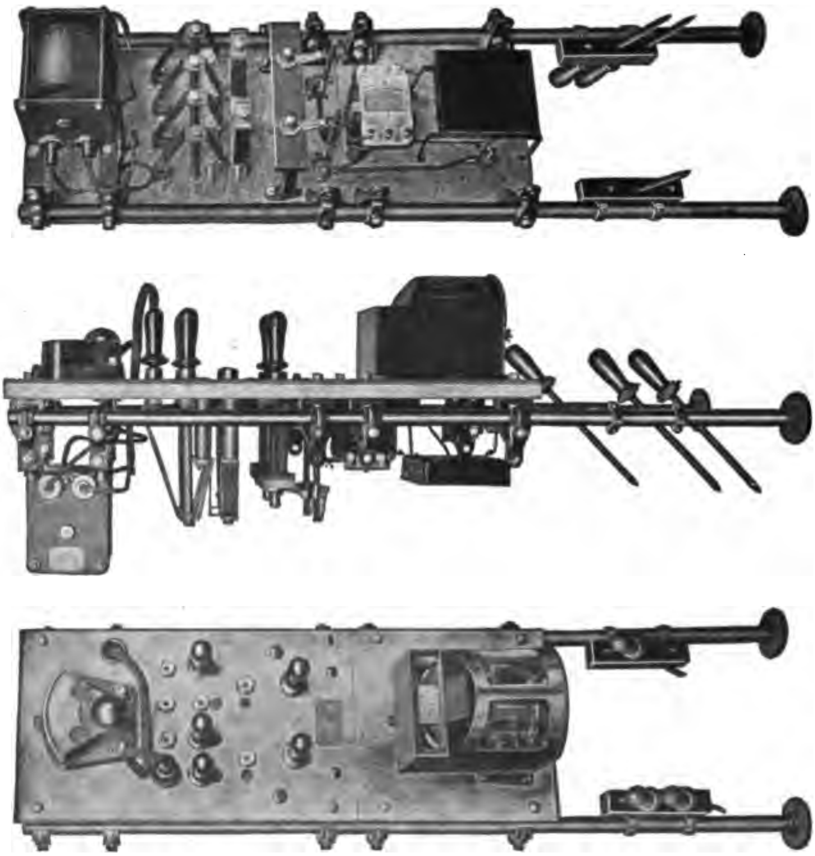


Fig. 27.

the same bedplate. The generator may be shunt or compound wound, as desired. Rotary converters are direct-current generators, though specially designed; they are fitted with collector rings attached to the winding at definite points. The alternating current is fed into these rings and the machine runs as a synchronous motor, while direct current is delivered at the commutator end. There is a fixed relation between the voltage applied to the alternating-current side and the direct-current voltage, which depends on the shape of the wave form, losses in the armature, pole pitch of the machine, method of connection, etc. The generally accepted values are as follows:

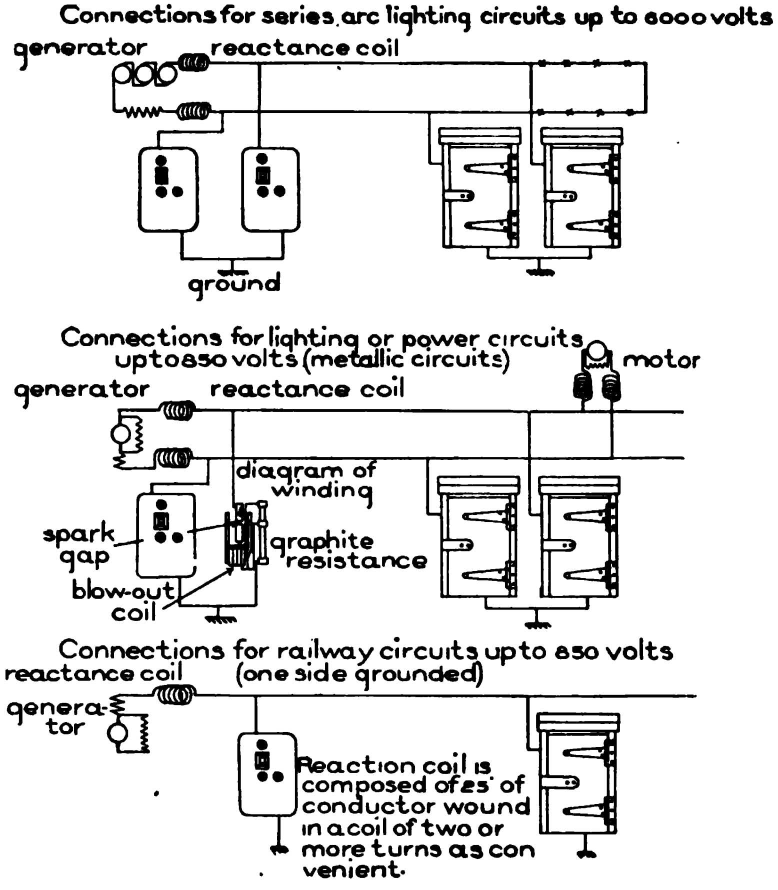
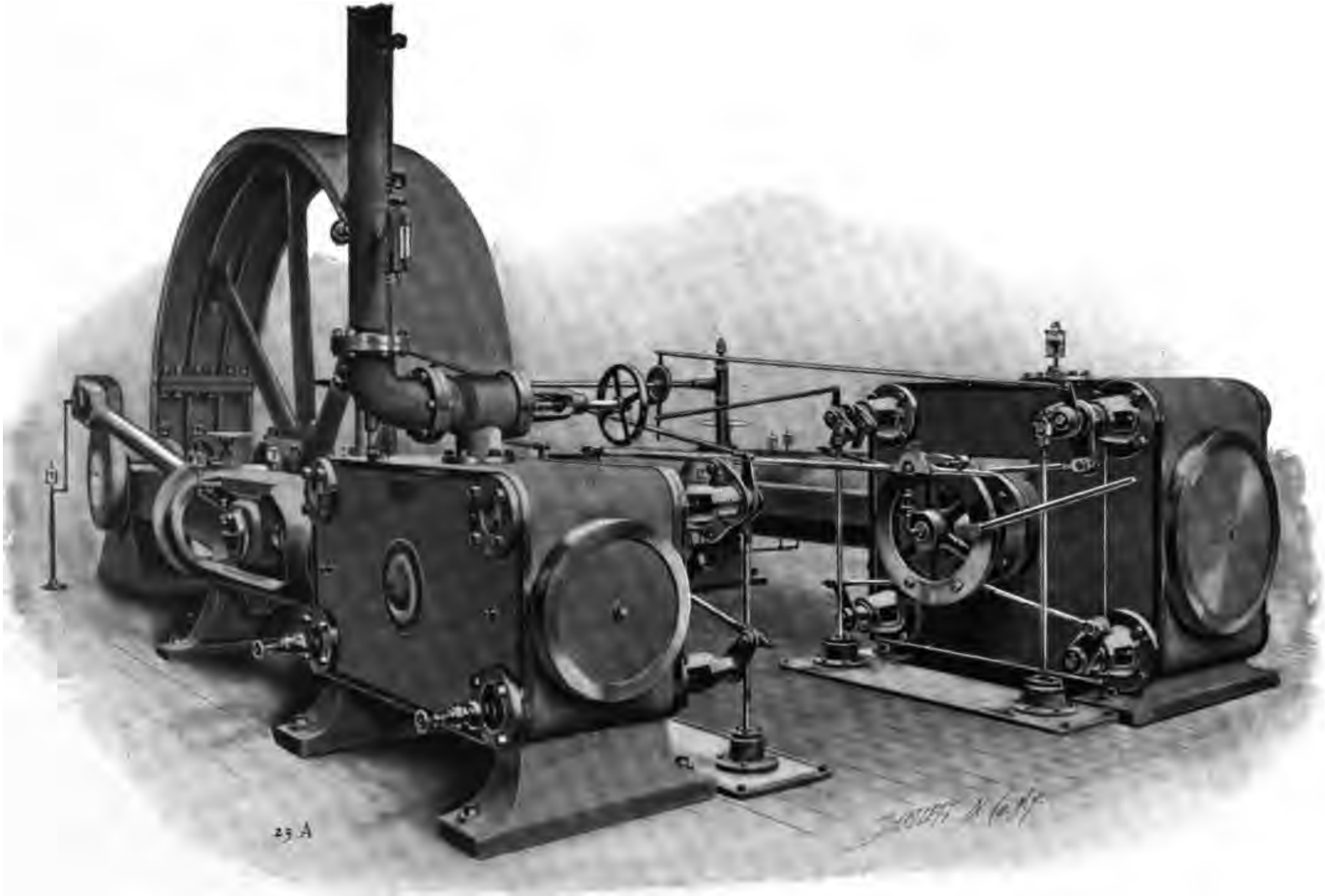

Connections for series arc lighting circuits up to 6000 volts
generator
reactance coil
ground
Connections for lighting or power circuits up to 650 volts (metallic circuits)
motor
generator
reactance coil
diagram of winding
spark gap
graphite resistance
blow-out coil
Connections for railway circuits up to 650 volts (one side grounded)
reactance coil
generator
Reaction coil is composed of 25' of conductor wound in a coil of two or more turns as convenient.

Fig. 28.



COMPOUND CORLISS ENGINE.

Frick Company.

TABLE 13.

Full Load Ratios.

Current.		Potential.
Continuous		100
Two-phase and Six-phase (diametrical)	550 volts	72.5
	250 "	73
	125 "	73.5
Three-phase and Six-phase (Y or delta)	550 "	62
	250 "	62
	125 "	63

The increase of capacity of six-phase machines over other machines of the same size is given in Table 14.

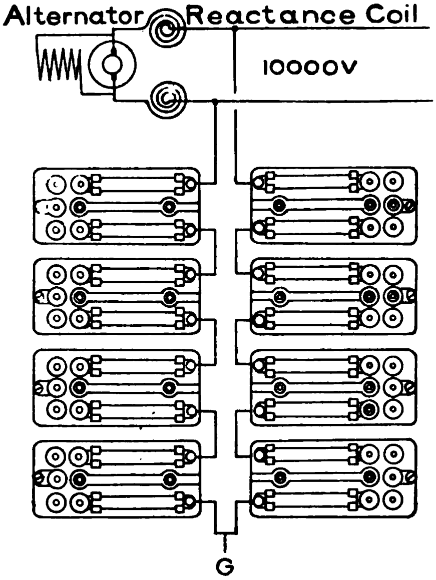


Fig. 29.

This increase is due to the fact that, with a greater number of phases, less of the winding is traversed by the current which passes through the converter. The saving by increasing the number of phases beyond six is but slight and the system becomes too complex. Rotary converters may be over-compounded by the addition of series fields, provided the reactance in the alternating circuits be of a proper value. It is customary to insert reactance coils in the leads from the low-tension side of the step-down transformers to the collector rings to bring the reactance to a value which will insure the desired compounding. Again, the voltage may be controlled by means of induction regu-

TABLE 14.

Capacity Ratios.

Continuous-current generator	100
Single-phase converter	85
Two-phase converter	164
Three-phase converter	134
Six-phase converter	196

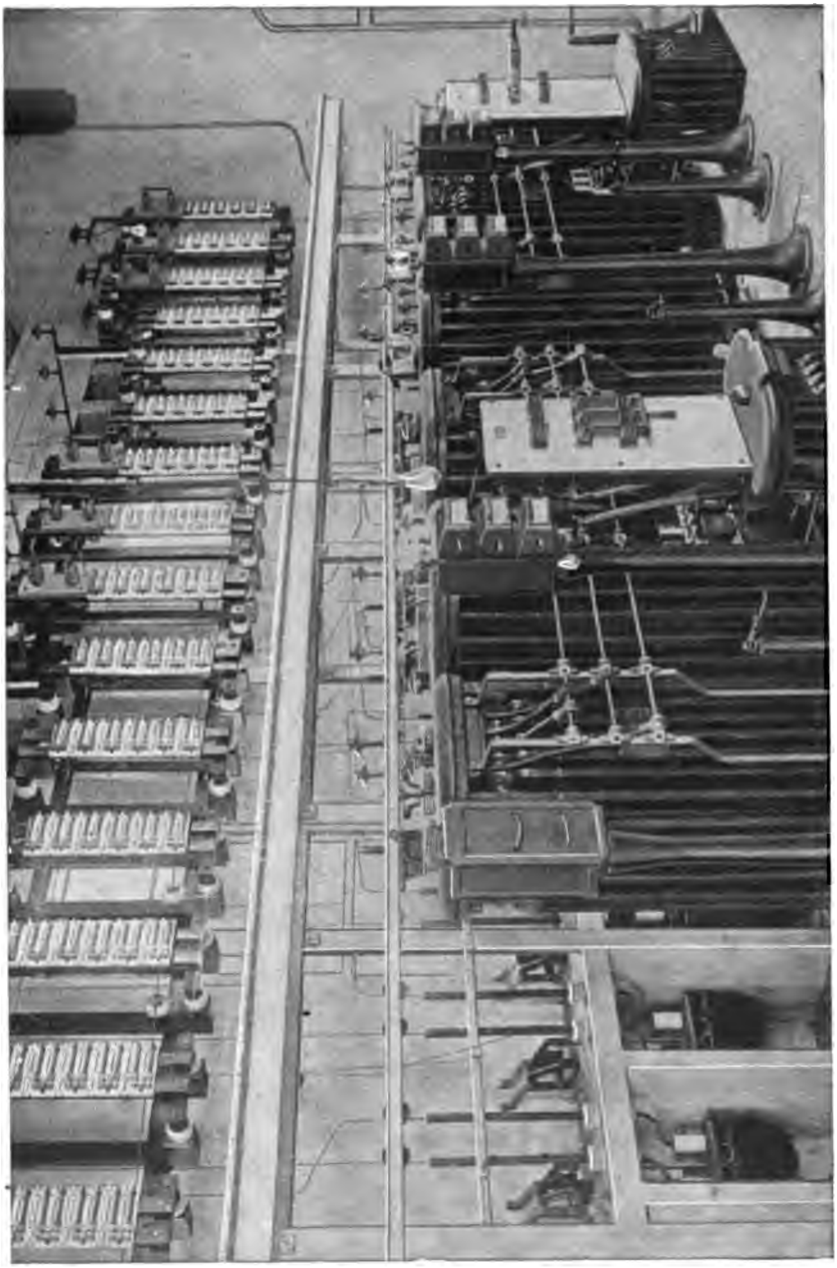


Fig. 30. 28,400-Volt Lightning Arrester Installation.

lators placed in the alternating-current leads. Motor-generators are more costly and occupy more space than rotary converters, but the regulation of the voltage is much better and they are to be preferred for lighting purposes.

Buildings. The power station usually has a building devoted entirely to this work, while the substations, if small, are often made a part of other buildings. While the detail of design and construction of the buildings for power plants belongs primarily to the architect, it is the duty of the electrical engineer to arrange the machinery to the best advantage, and he should always be consulted in regard to the general plans at least, as this may save much time and expense in the way of necessary modifications. The general arrangement of the machinery will be taken up later, but a few points in connection with the construction of the buildings and foundations will be considered here.

Space must be provided for the boiler,—this may be a separate building—engine and dynamo room, general and private offices, store rooms and repair shops. Very careful consideration should be given to each of these departments. The boiler room should be parallel with the engine room, so as to reduce the necessary amount of steam piping to a minimum, and if both rooms are in the same building a brick wall should separate the two, no openings which would allow dirt to come from the boiler room to the engine room being allowed. The height of both boiler and engine rooms should be such as to allow ample headway for lifting machinery and space for placing and repairing boilers, while provision should be made for extending these rooms in at least one direction. Both engine and boiler rooms should be fitted with proper traveling cranes to facilitate the handling of the units. In some cases the engines and dynamos occupy separate rooms, but this is not general practice. Ample light is necessary, especially in the engine rooms. The size of the offices, store rooms, etc., will depend entirely on local conditions.

The foundations for both the walls and the machinery must be of the very best. It is well to excavate the entire space under the engine room to a depth of eight to ten feet so as to form a basement, while in most cases the excavations must be made to a greater depth for the walls. Foundation trenches are sometimes

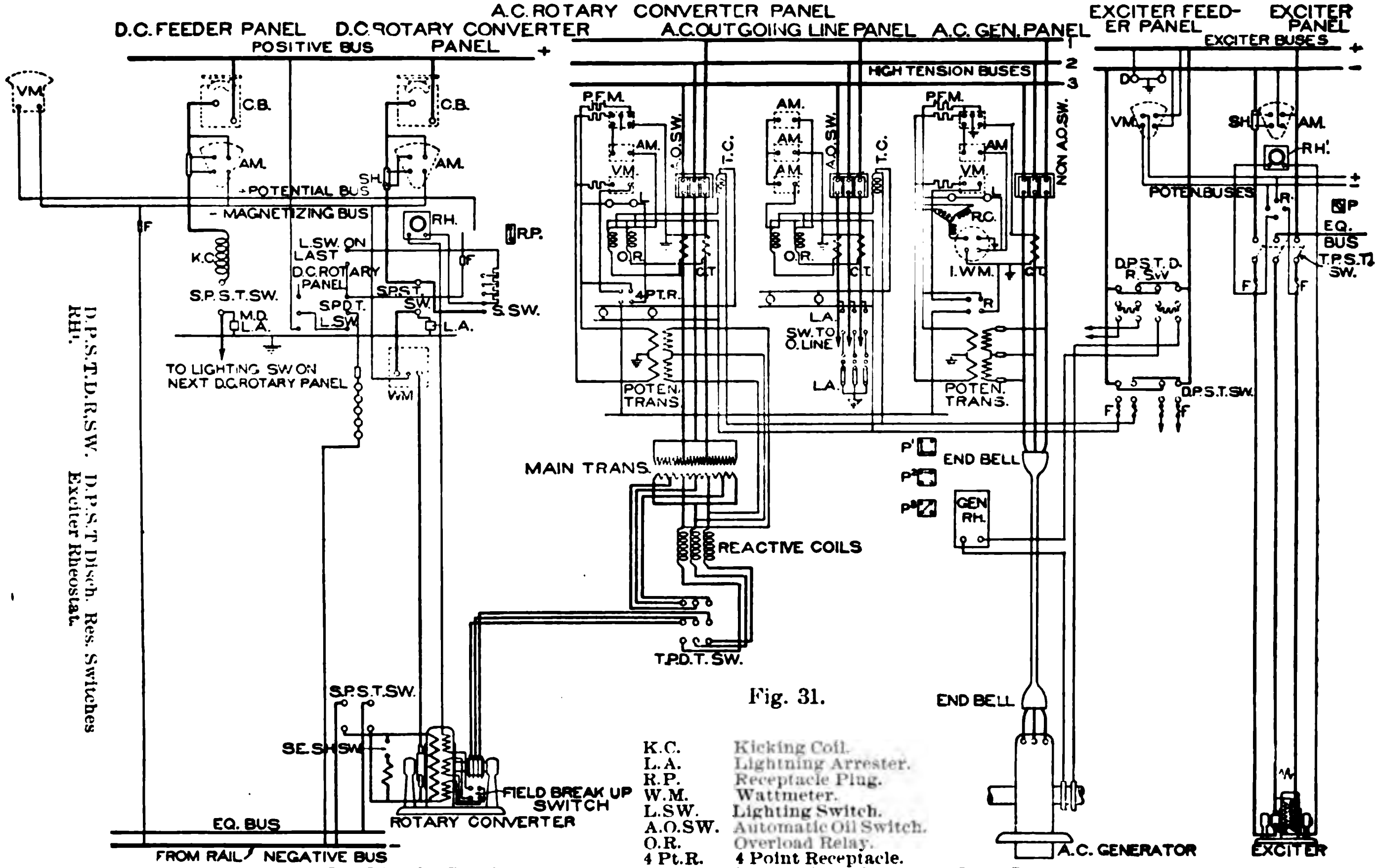


Fig. 31.

RH.	Rheostat.	P₂	Plug for Reading Voltage.
P₁	Plug for Machine Starting.	P₃	Plug for Machine Running.

K.C.	Kicking Coil.
L.A.	Lightning Arrester.
R.P.	Receptacle Plug.
W.M.	Wattmeter.
L.SW.	Lighting Switch.
A.O.SW.	Automatic Oil Switch.
O.R.	Overload Relay.
4 Pt.R.	4 Point Receptacle.
C.T.	Current Transformer.
T.C.	Tripping Coil.
I.	Lamps.
R.C.	Reactive Coils.
R.	Receptacle.
D.	Detector.
D.P.S.T.D.R.SW.	D.P.S.T Disch. Res. Switches
RH¹.	Exciter Rheostat.

filled with concrete to a depth sufficient to form a good underfooting. The area of the foundation footing should be great enough to keep the pressure within a safe limit for the quality of the soil.

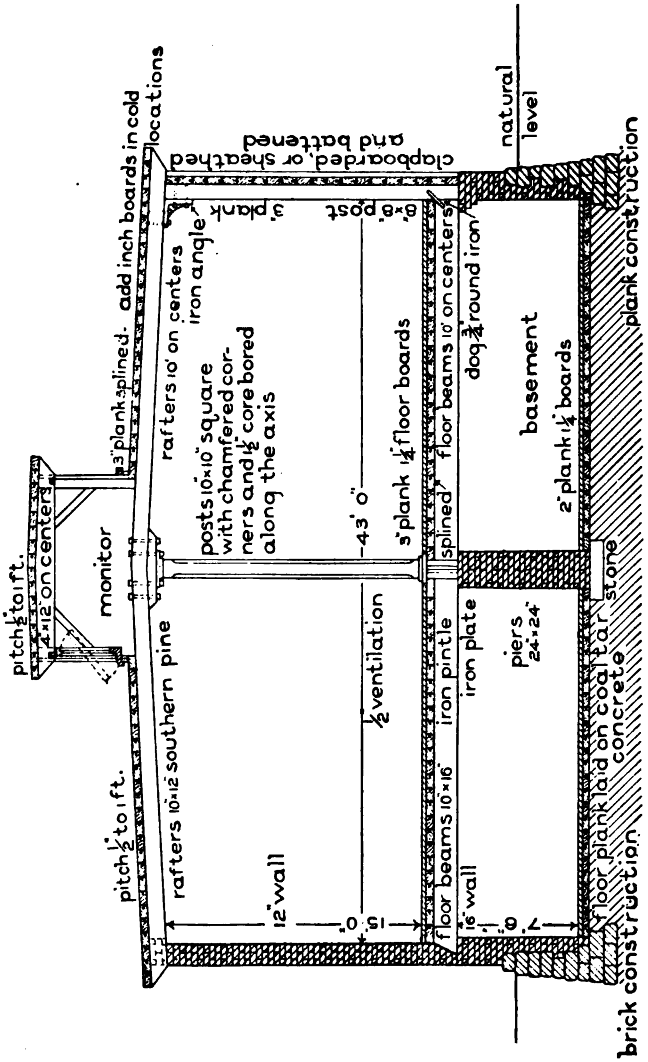


Fig. 32.

The walls themselves may be of wood, brick, stone, or concrete. Wood is used for very small stations only, while brick may be used alone or in conjunction with steel framing, the latter construction being used to a considerable extent. If brick alone is used, the walls should never be less than twelve inches thick, and eighteen to twenty inches is better for large buildings. They must be amply reinforced with pilasters. Stone is used only for the most expensive stations. The interior of the walls is formed of glazed brick, when the expense of such construction is warranted. In fireproof construction, which is always desirable for power stations, the roofs are supported by steel trusses and take a great variety of forms. Fig. 32 shows what has been recommended as standard construction for lighting stations, showing both brick and wood construction. The floors of the engine room should be made of some material which will not form grit or dust. Hard tile, unglazed, set in cement or wood floors, is desirable. Storage battery rooms should be separate from all others and should have their interior lined with some material which will not be affected by the acid fumes. The best of ventilation is desirable for all parts of the station, but is of particular importance in the dynamo room if the machines are being heavily loaded. Substation construction does not differ from that of central stations when a separate building is erected. They should be fireproof if possible.

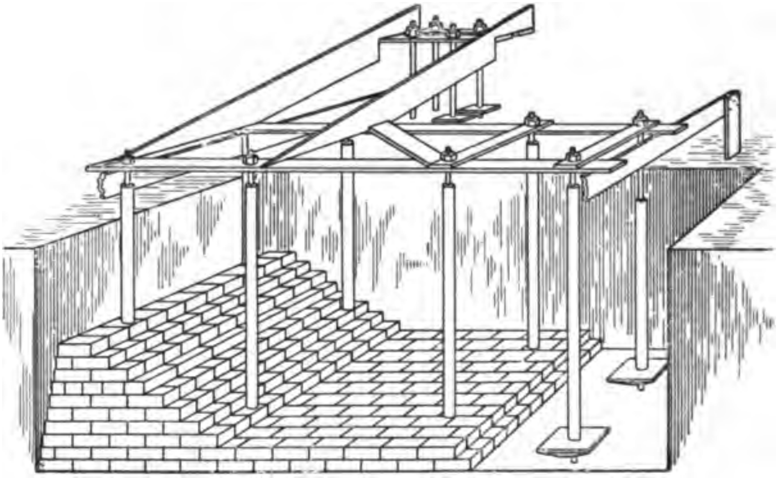
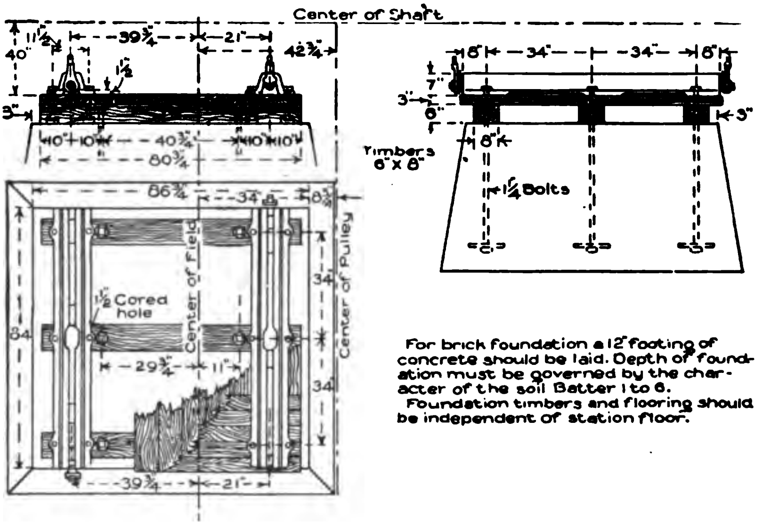


Fig. 33.

The foundations for machinery should be entirely separate from those of the building. Not only must the foundations be stable, but in some locations it is particularly desirable that no vibrations be transmitted to adjoining rooms and buildings. A loose or sandy soil does not transmit such vibrations readily, but firm earth or rock transmits them almost perfectly. Sand, wool, hair, felt, mineral wool, and asphaltum concrete are some of the materials used to prevent this. The excavation for the foundation is made from two to three feet deeper and two to three feet wider on all sides than the foundation, and the sand, or whatever material is used, occupies this extra space.

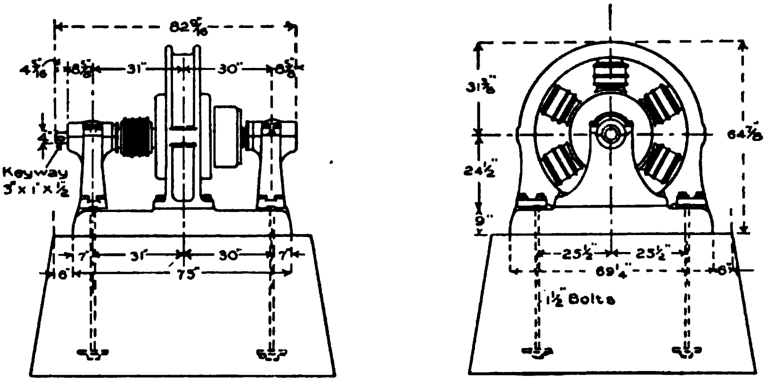


For brick foundation a 12" footing of concrete should be laid. Depth of foundation must be governed by the character of the soil Batter 1 to 6.

Foundation timbers and flooring should be independent of station floor.

Fig. 34.

Brick, stone, or concrete is used for building up the greater part of machinery foundations, the machines being held in place by means of bolts fastened in masonry. A template, giving the location of all bolts to be used in holding the machine in place, should be furnished, and the bolts may be run inside of iron pipes with an internal diameter a little greater than the diameter of the bolt. This allows some play to the bolt and is convenient for the final alignment of the machine. Fig. 33 gives an idea of this construction. The brickwork should consist of hard-burned brick of the best quality, and should be laid in cement mortar. It is well to fit brick or concrete foundations with a stone cap, forming a level surface on which to set the machinery, though this is not necessary. Generators are sometimes mounted on wood bases to furnish insulation for the frame. Fig. 34 shows the foundation for a 150 K.W. generator, while Fig. 35 shows the foundation for a rotary converter.



For brick foundation a 12" footing of concrete should be laid Depth of foundation must be governed by the character of the soil. Batter 1 to 6.

Fig. 35.

Station Arrangement. A few points have already been noted in regard to station arrangement, but the importance of the subject demands a little further consideration. Station arrangement depends chiefly upon two facts—the location and the machinery to be installed. Undoubtedly the best arrangement is with all of the machinery on one floor with, perhaps, the operating switchboard mounted on a gallery so that the attendants may have a clear view of all the machines. Fig. 36 shows the simplest arrangement of a plant using belted machines. Fig. 37 shows an arrangement of units where a jack shaft is used. Direct-current machines should be placed so that the brushes and commutators are easily accessible and the switchboard should be placed so as to not be liable to accidents, such as the breaking of a belt or a fly-wheel.

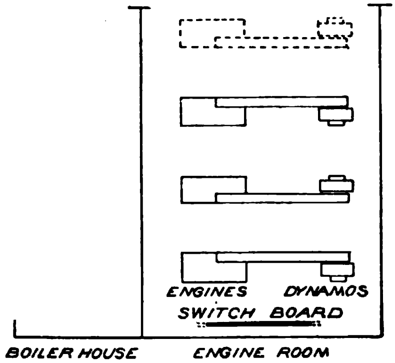


Fig. 36.

When the cost of real estate prohibits the placing of all of the machinery on one floor, the arrangements shown in Fig. 38 may be used when the machines are belted. It is always desirable to have the engines on the main floor, as they cause considerable vibration when not mounted on the best of foundations. The boilers, while heavy, do not cause such vibration and they may be placed on the second or third floor. Belts should not be run vertically, as they must be stretched too tightly to prevent slipping.

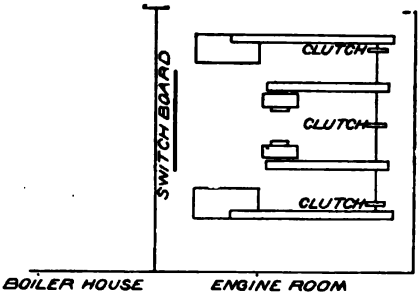


Fig. 37.

Fig. 39 shows a large station using direct-connected units, while Fig. 40 shows the arrangement of the turbine plant of the Boston Edison Electric Illuminating Company. This station will contain twelve such 5,000 K.W. units when completed. Note the arrangement of boilers when several units are required for a single prime mover. The use of a separate room or building for the cables, switches, and operating boards is becoming quite common for high-tension generating plants. The remarkable saving in floor space brought about by the turbine is readily seen from Fig. 41. The total floor space occupied by the new Boston station is 2.64 square feet per K.W. This includes boilers—of which there are eight, each 512 H.P. for each unit—turbines, generators, switches, and all auxiliary apparatus.

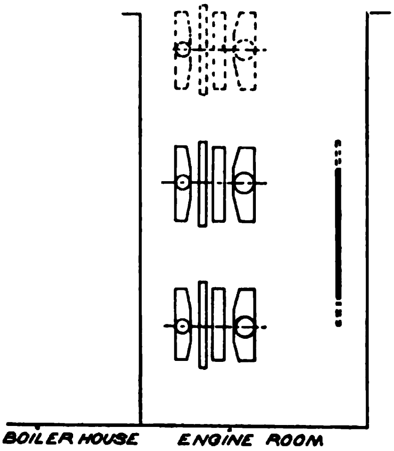


Fig. 39.

When transformers are used for raising the voltage, they may be placed in a separate building, as is the case at Niagara Falls, or the transformers may be located in some part of the dynamo room, preferably in a line parallel to the generators.

Fig. 42 shows the arrangement of units in an hydraulic plant. Fig. 43 is a good example of the practice in substation arrangement. Here the switchboard is mounted at one end of the room, while the rotary converters and transformers are arranged along either side of the building.

Large cable vaults are installed at the stations operating on underground systems, the separate ducts being spread out, and sheet-iron partitions erected to prevent damage being done to cables which were not originally defective, by a short circuit in any one feeder.

Station Records. In order to accurately determine the cost of generating power and to check up on uneconomical or improper methods of operation and lead to their improvement, accurately kept station records are of the utmost importance. Such records should consist of switchboard records, engine-room records, boiler-room records, and distributing-system records. Such records accurately kept and properly plotted in the form of curves, serve admirably for the comparison of station operations from day to day and for the same periods for different years. It pays to keep these records even when additional clerical force must be employed.

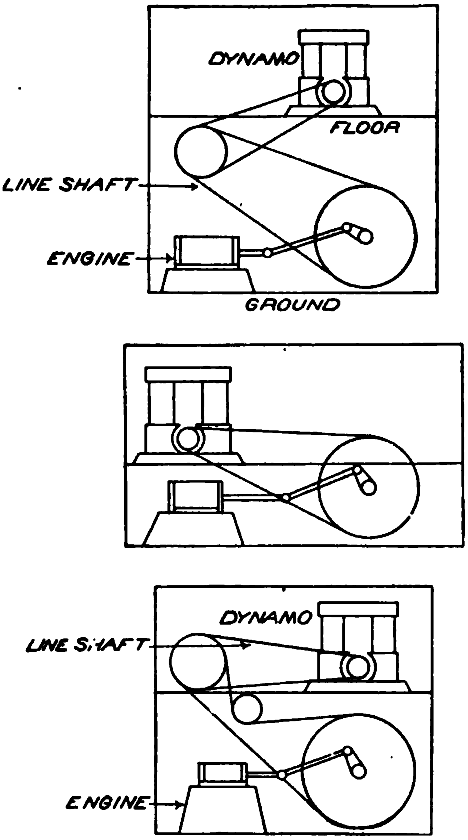
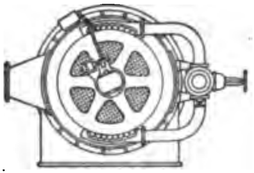


Fig. 38.

Switchboard records consist, in alternating stations, of daily readings of feeder, recording wattmeters, and total recording wattmeter, together with voltmeter and ammeter readings at intervals of about 15 minutes in some cases to check upon the average power factor and determine the general form of the load curve. For direct-current lighting systems volt and ampere readings serve to give the true output of the stations, and curves are readily plotted from these readings. The voltage should be recorded for the bus bars as well as for the centers of distribution.



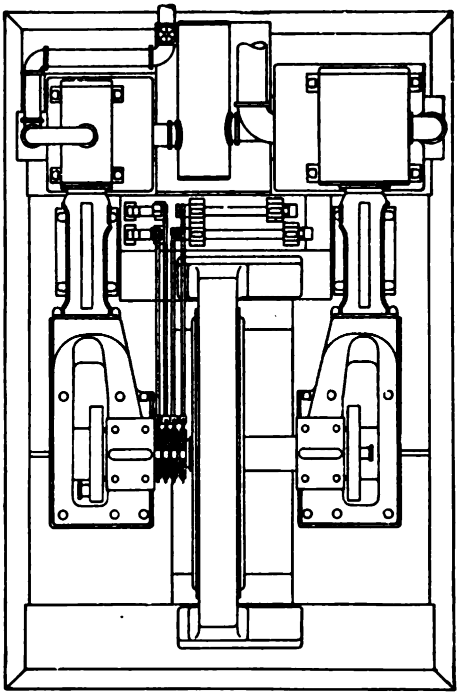


Fig. 41. Comparison of 1500 KW. Corliss Engine and 1500 KW. Curtis Turbine.

Indicator diagrams should be taken from the engines at frequent intervals for the purpose of determining the operation of the valves. Engine-room records include labor, use of waste oil and supplies, as well as all repairs made on engines, dynamos and auxiliaries.

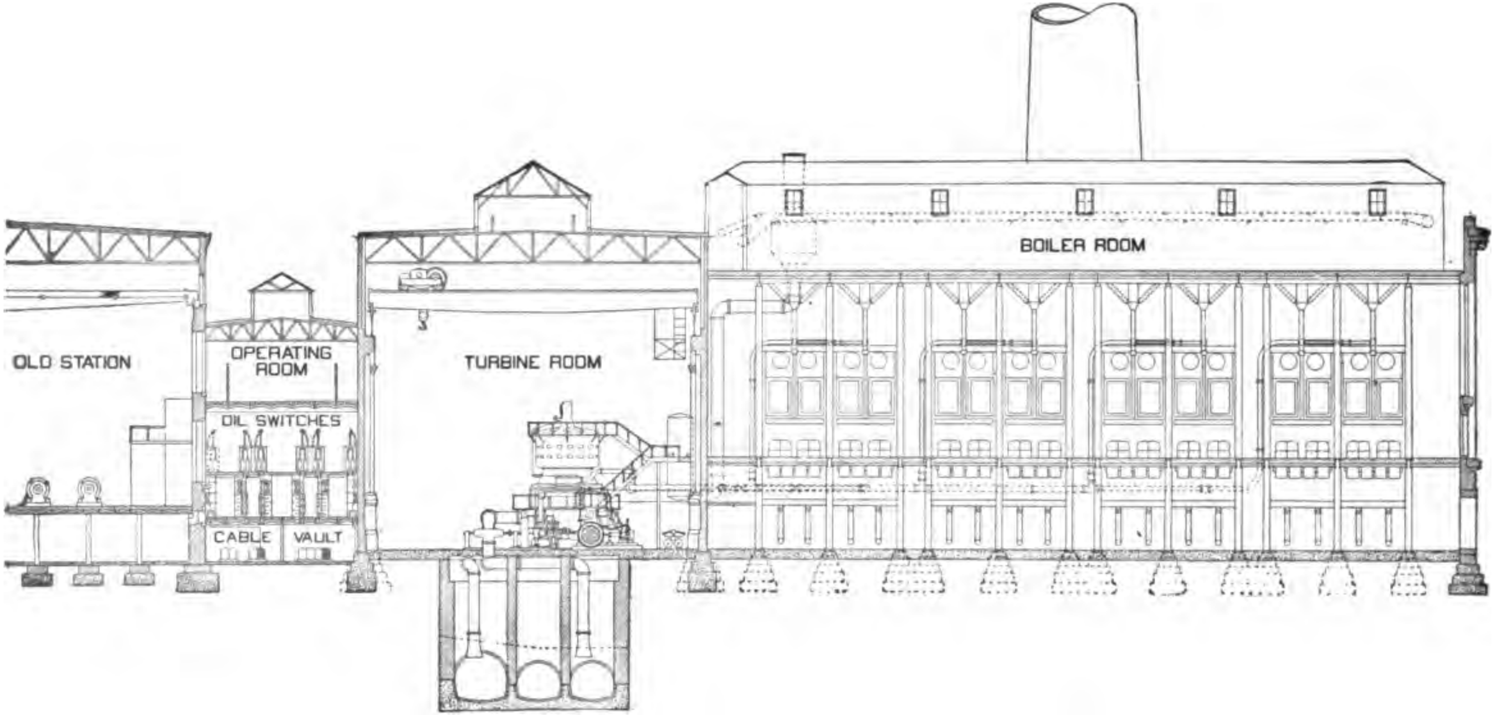

OLD STATION
OPERATING ROOM
OIL SWITCHES
CABLE
VAULT
TURBINE ROOM
BOILER ROOM

Fig. 40.

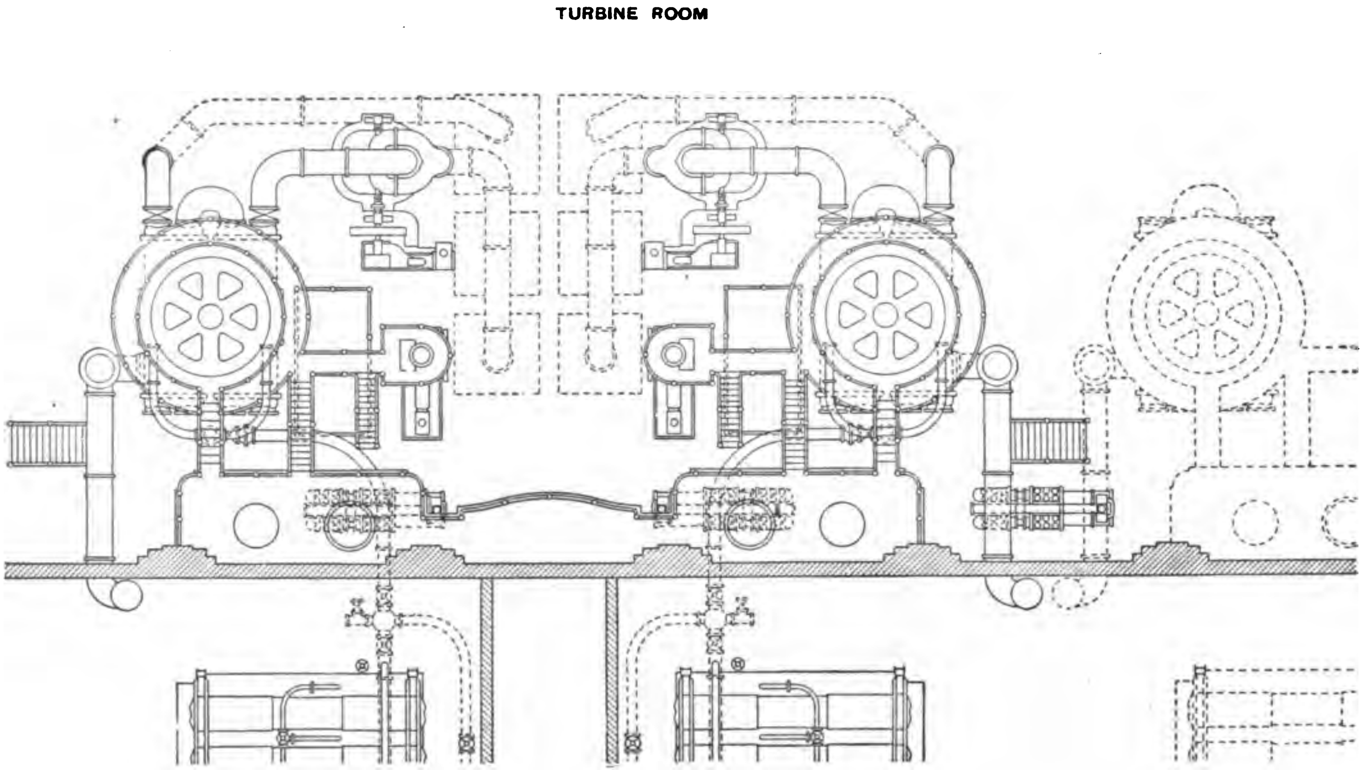


Fig. 40.

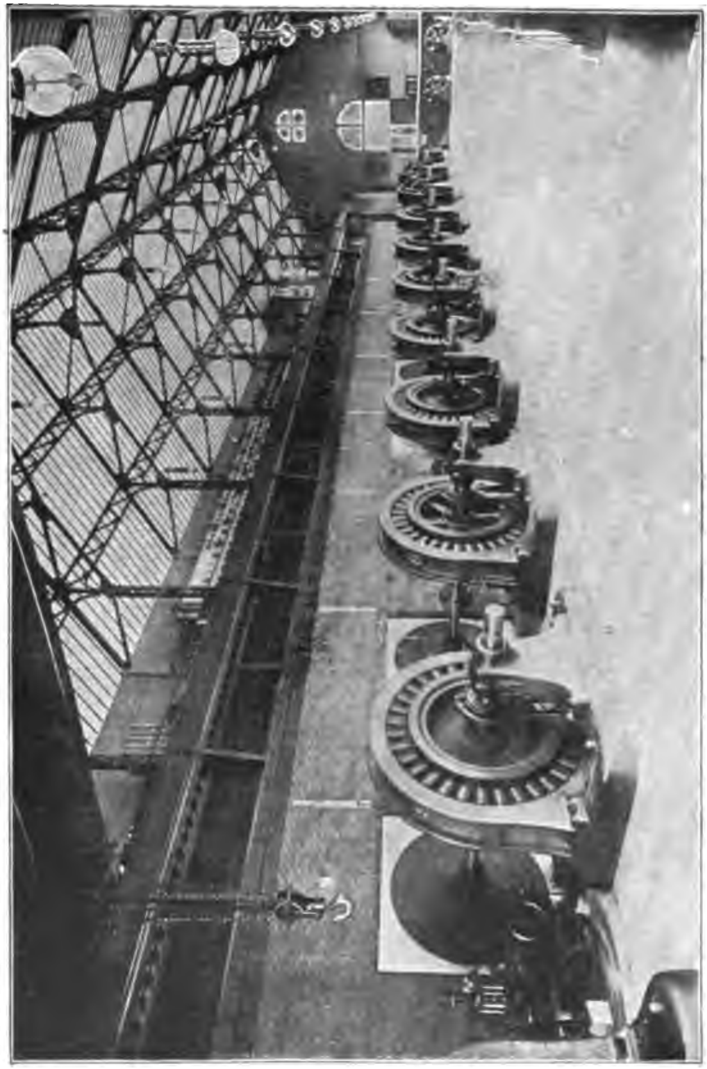


Fig. 42.

Boiler-room records include labor and repairs, amount of coal used, which amount may be kept in detail if desirable, amount of water used, together with steam-gauge record and periodical analysis of flue gases as a check on the methods of firing.

Records for the distributing system include labor and material used for the lines and substations. For multiple-wire systems, frequent readings of the current in the different feeders will serve as a check on the balance of the load.

The cost of generating power varies greatly with the rate at which it is produced as well as upon local conditions. Station operating expenses include cost of fuel, water, waste, oil, etc., cost of repairs, labor, and superintendence. Fixed charges include, insurance, taxes, interest on investment, depreciation, and general office expenses. Total expenses divided by total kilowatt hours gives the cost of generation of a kilowatt hour. The cost of distributing a kilowatt hour may be determined in a similar manner. The rate of depreciation of apparatus differs greatly with different machines, but the following figures may be taken as average values, these figures representing percentage of first cost to be charged up each year:

Fireproof buildings from 2 to 8 per cent.
Frame buildings from 5 to 8 per cent.
Dynamos from 2 to 4 per cent.
Prime movers from 2½ to 5 per cent.
Boilers from 4 to 5 per cent
Overhead lines, best constructed, 5 to 10 per cent.
More poorly constructed lines 20 to 30 per cent
Badly constructed lines 40 to 60 per cent
Underground conduits 2 per cent.
Lead covered cables 2 per cent.

Methods of Charging for Power. There are four methods used for charging consumers for electrical energy, namely, the flat-rate or contract system, the meter system, the two-rate meter system, and a system by which each customer pays a fixed amount depending on the maximum demand and in addition pays at a reasonable rate for the power actually used. In the flat-rate system, each customer pays a certain amount a year for service, this amount being based on the estimated amount of power to be used. These rates vary, depending on the hours of the day during which the power is to be used, being greatest if the energy is to be used during peak hours. It is an unsatisfactory method for lighting service, as many customers are liable to take advantage of the company, burning more lights than contracted for and at different hours, while the honest customer must pay a higher rate than is reasonable in order to make the station operation profitable.

This method serves much better when the power is used for driving motors, and is used largely for this class of service.

The simple meter method of charging serves the purpose better for lighting, but the rate here is the same no matter what hour of the day the current is used. Obviously, since machinery is installed to carry the peak of the load, any power used at this time tends to increase the capital outlay from the plant, and users should be required to pay more for the power at such times.

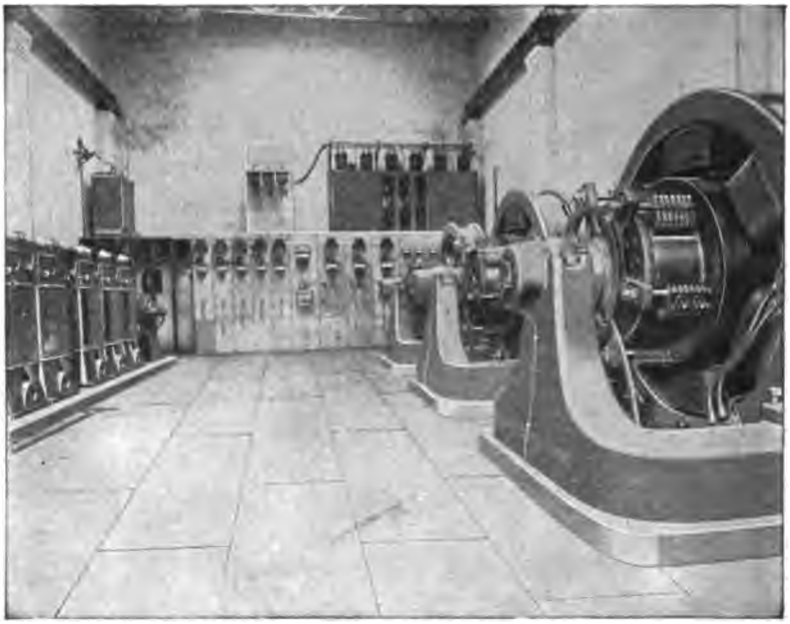
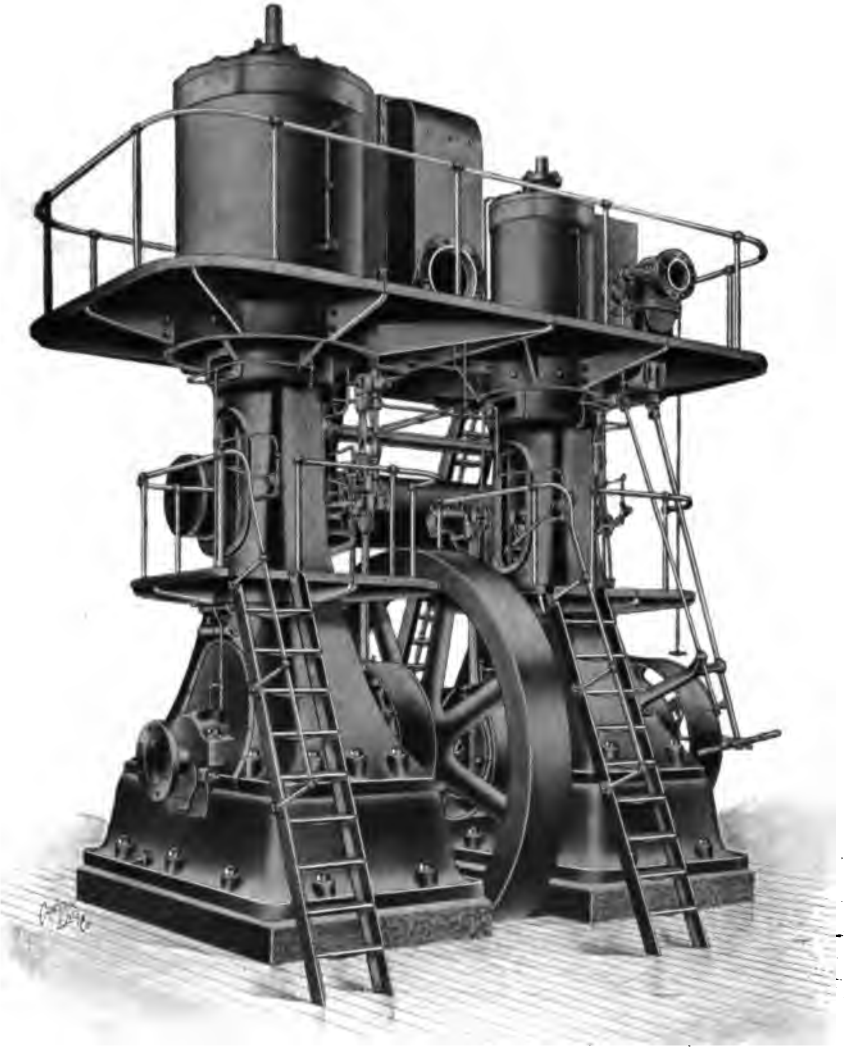


Fig. 43.

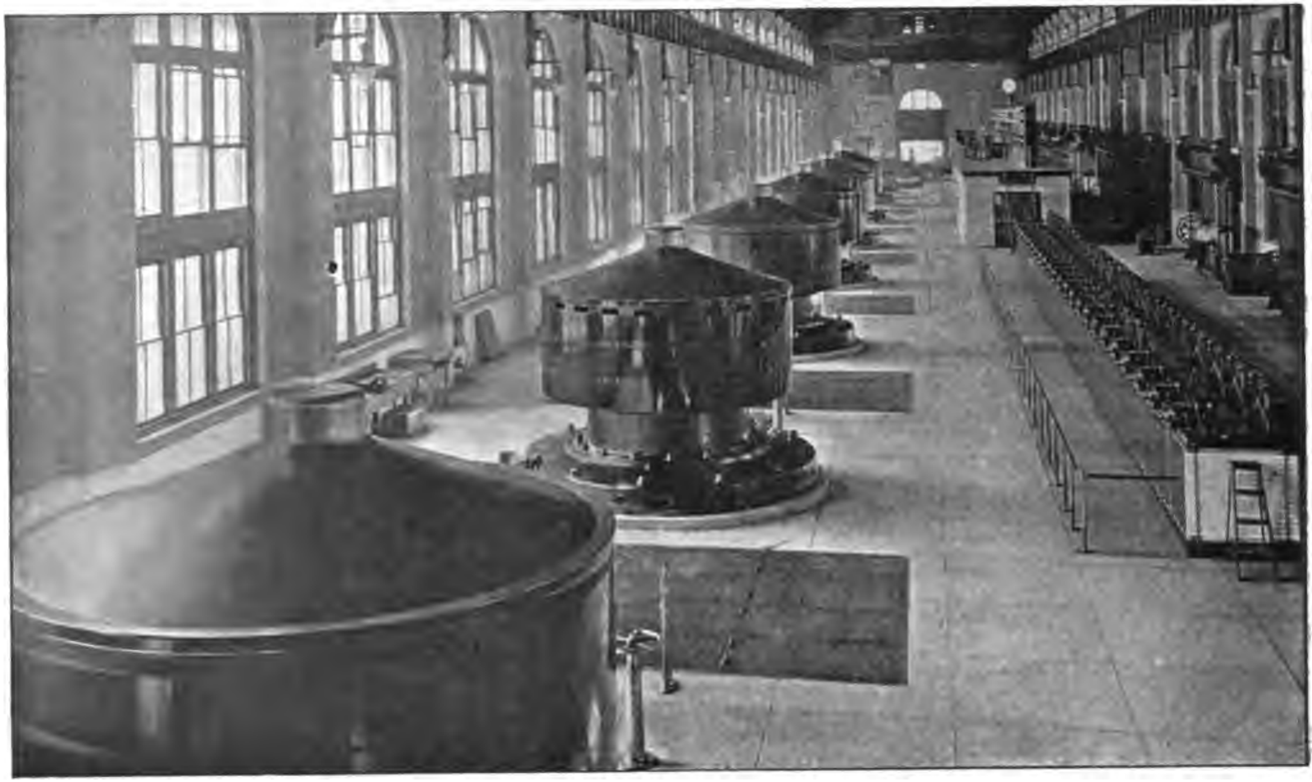
The two-meter rate accomplishes this purpose to a certain extent. The meters are arranged so that they record at two rates, the higher rate being used during the hours of heavy load.

There are several methods of carrying out the fourth scheme. In the Brighton System, a fixed charge is made each month, depending on the maximum demand for power during the previous month, a regular schedule of such charges being made out, based on the cost of the plant. An integrating wattmeter is used to record the energy consumed, while a so-called "demand meter" records the maximum rate of demand.



HEAVY-DUTY VERTICAL CROSS-COMPOUND ENGINE.

Buckeye Engine Company.



POWER HOUSE NO. 2, NIAGARA FALLS POWER CO.

Eleven Generators of 5,000 H.P. Each.

A QUARTER CENTURY OF AMERICAN CENTRAL STATION ENGINEERING.

Perhaps few of the younger generation engaged in the various branches of electrical work realize that the central-station industry, so large and permanent an institution of our present civic life, is barely a quarter of a century old. Marvelous, indeed, has been the progress of this industry, and its wheels of invention and development are stilling whirling rapidly on. No engineer who values his reputation would venture to prophesy what the next quarter-century will bring us.

Twenty-five years ago the commercial electric lamp was unknown. To-day there are in service in the United States alone nearly twenty million incandescent lamps, to say nothing of the tens of thousands of arc lamps and the few hundred thousand horse-power in electric motors. To-day nearly every city of any importance in America has an electric plant furnishing light and power to its citizens. Magnificent stations have sprung up in our large cities, representing millions of dollars in investment; and electricity is being distributed to nearly every corner of those cities. It may be of interest, then, to look back over the history of this industry, and see some of the steps by which it reached its present splendid growth.

In all the world's history of industrial progress, perhaps no chapter is more full of scientific and heroic romance than that dealing with the birth of the electric-light industry. To the youth of to-day no story could give greater inspiration than that of the men who were the leading figures—the great minds and the energetic workers—during the early days of central-station development. These men contributed as much toward the nation's growth as did our warriors and our statesmen. Most of them are still with us, and are still active in solving engineering problems. It was the good fortune of the readers of the *Electrical World and Engineer* to see, in its recent thirtieth anniversary issue, some interesting reminiscences of these early workers, and thus have brought home to them the youthful age of the industry. It is not the purpose of this paper, however, to relate biography, but rather to treat of the more prosaic subject of the growth of the central station from its small beginnings to the magnificent proportions of to-day.

BRUSH ARC SYSTEM.

In 1879, there was erected in Cleveland, Ohio, a series-arc system designed by Charles F. Brush. The dynamo furnishing current for these lamps had been built by Brush during the preceding year. The electric arc itself had been discovered by Sir Humphry Davy in London about the year 1802, the source of current for his lamp being a battery of several thousand cells. As the dynamo had not at that time come into existence, the commercial importance of the discovery was not then apparent.

From this first system of Brush's, dates the history of commercial electric lighting in America. As stated, the lamps of this system were all connected in series, so that the same current passed through all of them. With many lamps on the circuit this required a fairly high voltage. The efforts of many investigators were then directed toward developing an incandescent lamp for these circuits so that the lights could be used indoors where the arc lamps would be too brilliant. In order to obtain a lamp requiring only a low voltage, which is a desirable feature in series connection, a lamp of low resistance is necessary.

EDISON CONSTANT-POTENTIAL SYSTEM.

The master mind of Thomas Edison soon saw that a series system with high voltage on each line would never become commercially successful for general house lighting; therefore he set about to design a system which should properly meet the required conditions. On February 5, 1880, he patented a constant-potential system consisting of feeders and mains, with the load connected in parallel, or multiple arc, between the two wires forming the positive and the negative conductors, as shown in Fig. 1. How well this succeeded is evidenced by the present almost universal use of this system of connection. Obviously, a low-resistance lamp would not do on a constant-potential circuit; Edison, therefore, first developed a high-resistance lamp. His success in this is well known. His patent for the lamp is dated November 4, 1879. In December of that year he had a number of these lamps on exhibition at his laboratory in Menlo Park, and the following year he equipped his house and grounds with the lamps. The newspapers of the time were filled with accounts of what the "Wizard of Menlo Park" had accomplished, and visitors flocked to the town in great numbers to see the lights.

The first Edison plant for the public supply of current was located at Appleton, Wisconsin, where in 1881, was installed one of the first of the lanky bipolar dynamos, connected by a belt to a water wheel in a little wooden shed. The first central station for general distribution of current to incandescent lamps was started January 12, 1882, at Holborn Viaduct in London, England. The second and the third Jumbo dynamos (so named because of their bulk), built by Edison in America, furnished the current for this system. They weighed twenty-three tons each, and had a combined capacity of 3,000 lights. The first of these machines built by Edison was sent to the Paris Exposition of 1881. By October, 1882, the Edison Manufacturing Company had installed in all 123 plants, with a total of about 22,000 lamps.

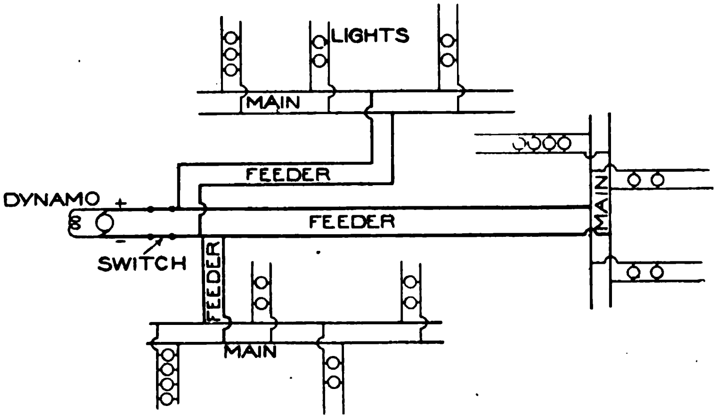


Fig. 1.

The Edison Tube. During this time Edison's attention had been directed toward laying out a system for the city of New York. In such a city it was desirable to have the system underground. Accordingly, the Edison tube was designed. This consisted of two half-round copper bars laid in iron pipe in lengths of about twenty feet, and insulated by means of a tar compound While there are still many miles of these tubes giving good service, all new underground work has for some years been done with lead-covered cables drawn into ducts laid in the streets, the connections being made in manholes. Fig. 2 shows a duct system made of cement-lined iron pipe laid in a bed of concrete.

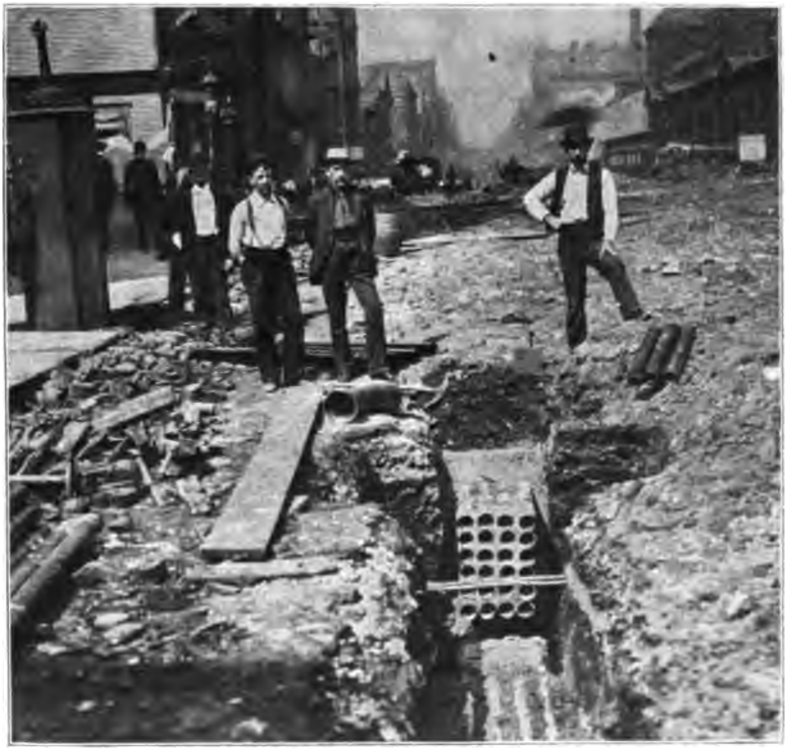


Fig. 2.

Three-Wire Direct-Current System. Late in 1882, Edison made a series of experiments with a view toward a more economical distribution system, and he then devised the well-known three-wire system, in which two generators are connected in series, and a conductor is connected to their junction, and run out into the system as the neutral wire. This is illustrated in Fig. 3. By connecting the lights so that the load on the two sides of the system is nearly balanced, a saving of about sixty per cent was effected in the amount of copper necessary to transmit the same energy. This is due to the fact that, in the three-wire system, the current is transmitted at 220 volts instead of at 110, thus requiring for the same number of watts only half as many amperes; and therefore a smaller wire can be used. If the load on the two sides of the system is not balanced, the difference between the current in the positive conductor and that in the negative will come back to the dynamos over the neutral wire. Dr. John Hopkinson, in England, and Werner von Siemens, in Germany, devised similar systems at about the same time.

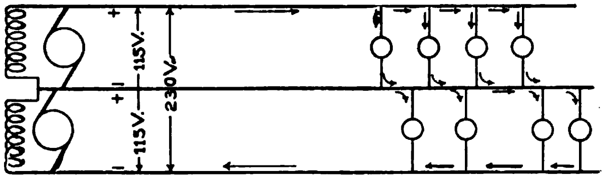


Fig. 3.

It was not until 1884 that electric motors were first used in New York; and the arc lamp designed for parallel connection on the constant-potential circuit was not introduced until 1889. The success of the constant-potential arc lamps made it possible for central stations to do all classes of business with one system of distribution—which was an important step in the march of progress. In 1890 the Duane Street Station was built in the heart of the Edison system, with a total engine capacity of 11,800 H.P. in direct-connected units.

In Boston, the Edison Electric Illuminating Company was organized in December, 1885, and the first station was started in February of the next year, using the Edison three-wire system of distribution. In 1887, a second station was built to take care of the load in another section of the city. Here, for the first time, was adopted the method of using 220-volt motors on the Edison system, connecting them to the two outer mains instead of between one outer and the neutral (110 volts), as had heretofore been done.

The Edison Companies. The good financial showing made by this company led to the formation of Edison Companies in many other cities, among the largest of which were Chicago and Philadelphia; and to the building of two up-town stations in New York. The original plant of the Western Edison Electric Light Company (now the Chicago Edison Company), a view of the dynamo room of which is shown in Fig. 4, was built at 139 Adams Street in 1887, and contained at first eight 100-K.W. Edison bipolar dynamos belted to four 250-H.P. engines located on the floor below. In 1891, additional dynamos and engines were added, until the total capacity reached 3,400 K.W.

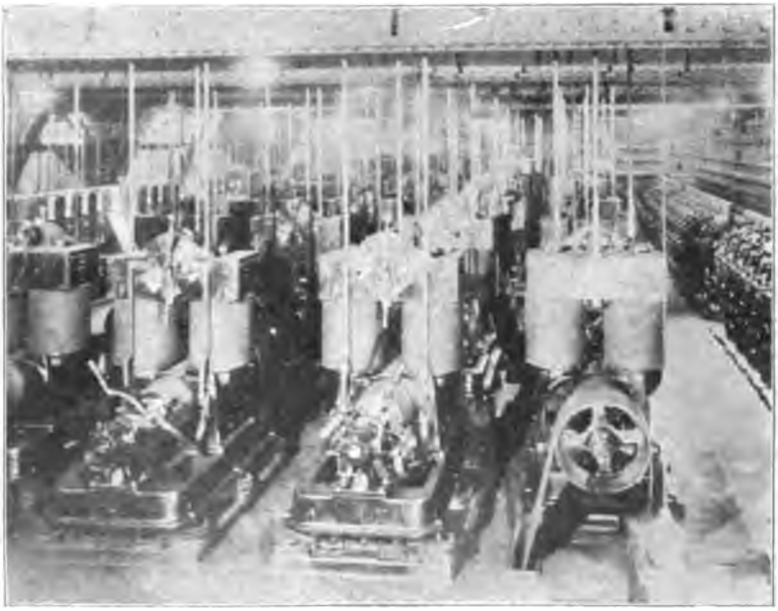


Fig. 4. Dynamo Room, Old Adams St. Station, Chicago Edison Co.

In the summer of 1892, the big station at Harrison Street, representing the most modern central-station engineering of the time, was started; and the next year the Adams Street Station was dismantled. The center of distribution, however, was kept at Adams Street, the current generated at the new station, about 3,000 feet away, being sent to this center over a trunk line consisting of twenty-eight Edison tubes and cables with a total sectional area of 66,000,000 circular mils. Of this, 9,000,000 c.m. of section was used for the neutral conductors, leaving 28,500,000 c.m. for each of the outsides, that is, for the positive and the negative.

In its onward march the Chicago Edison Company absorbed a number of plants, chief of which was that of the Chicago Arc Light & Power Company, located at Washington Street and the river. The systems operated from this station at that time consisted of series arcs, 500-volt direct current for power, and some 133-cycle 1,000-volt alternating-current lines. In 1894, there were added the Wabash Avenue Station near 27th Street on the South Side, with an Edison three-wire system and some series-arc lines; and the North Side Station at Clark and Oak Streets, which consisted solely of Edison generators connected to the usual three-wire system (Fig. 5). Fig. 6 is a view of the switchboard at Harrison Street Station. Fig. 6*a* is a back view of the generator gallery of this board, and shows the heavy copper bus bars. Fig. 7 is a cross-section of the engine and boiler rooms at Harrison Street Station, and Fig. 8 shows one of the 1,200-H.P. Southwark engines direct-connected to two 115-volt 400-K.W. generators. One of these dynamos connects with the positive, and the other with the negative, of the three-wire system.

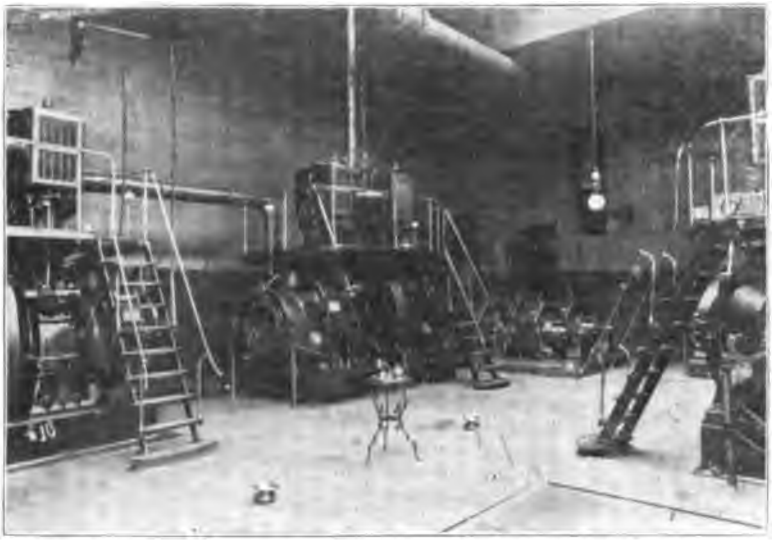


Fig 5. North Side Station, Chicago Edison Co.

Conservative Brooklyn waited to see what success was met by electric-light companies in other cities before its capitalists em-

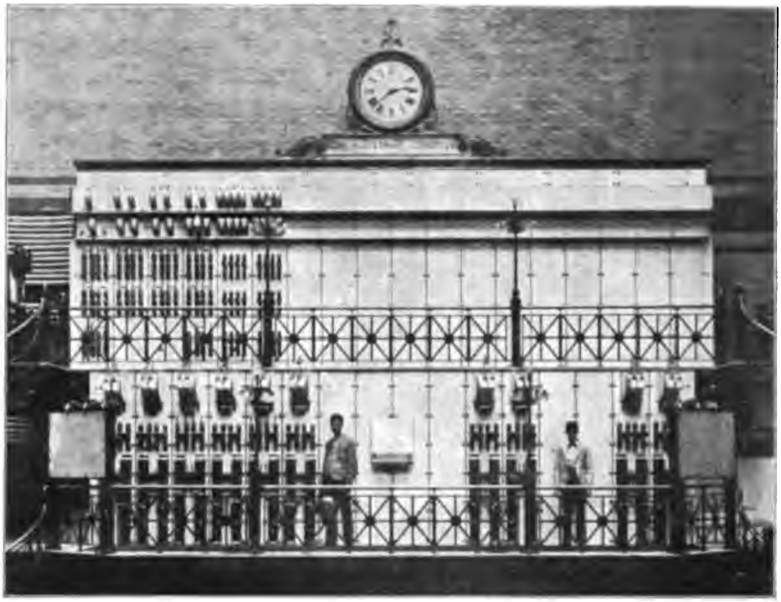


Fig. 6. Switchboard at Harrison Street Station.

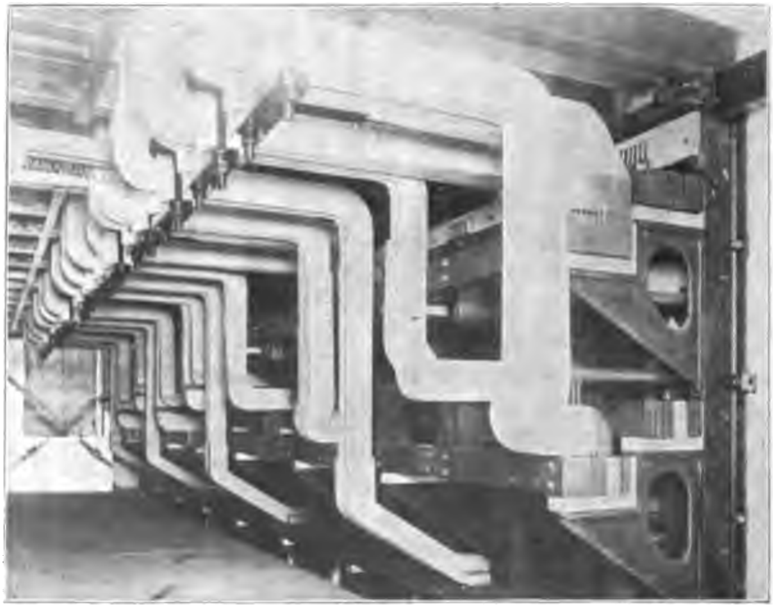


Fig. 6a. Back of Generator Gallery, Harrison Street Station.

barked on such enterprises, but in 1889 that city was added to the list of those having a central station for the production of electricity. In that year the Edison Electric Illuminating Company of Brooklyn built its first station on Pearl Street, and started operations with a load of 6,600 incandescent lamps connected to the system. The dynamos used were four of the Edison bipolar type of 100-K.W. capacity, each two of which were belted to a 250-H.P. cross-compound engine and were connected to an underground three-wire distribution system. In 1893, the station was remodeled, and larger dynamos were introduced direct-connected to vertical cross-compound condensing engines.

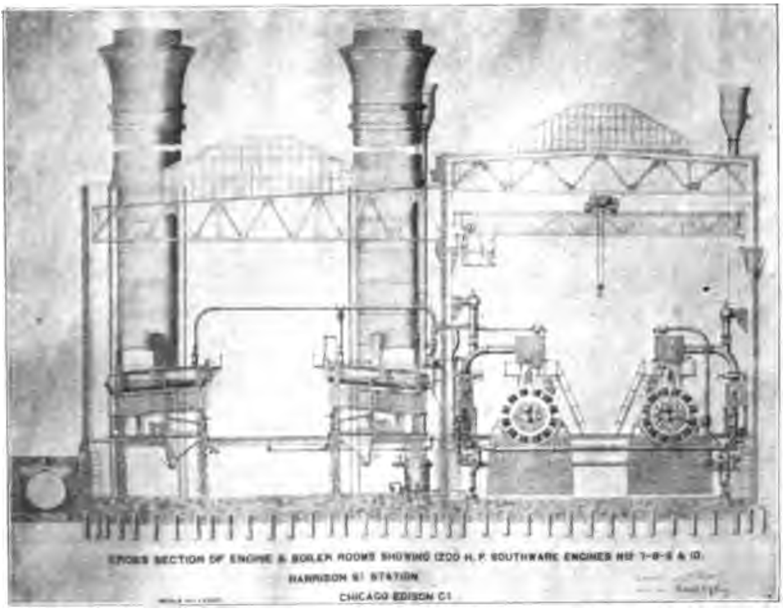
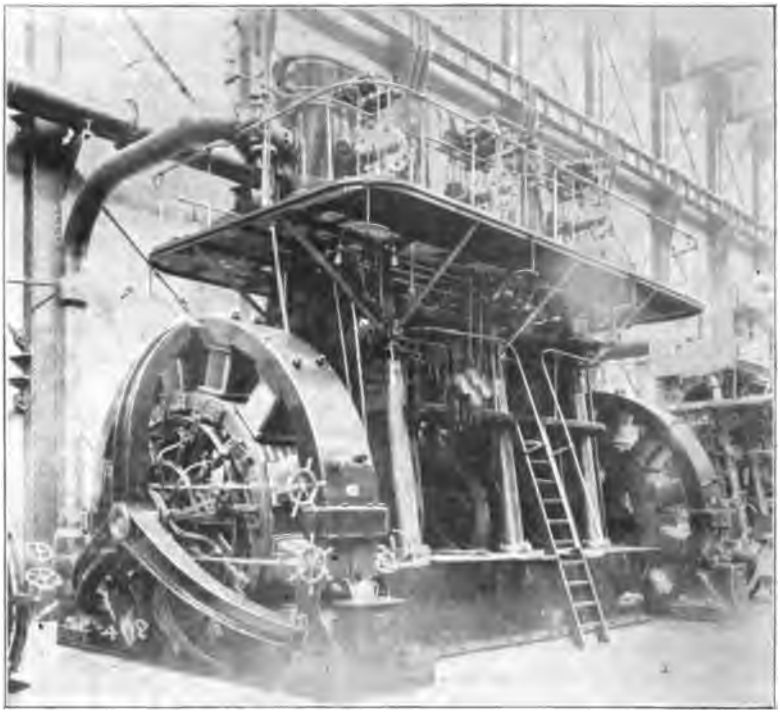

CROSS SECTION OF ENGINE & BOILER ROOMS SHOWING 1200 H.P. SOUTHWARK ENGINES NO 7-8-9 & 10.
HARRISON ST STATION
CHICAGO EDISON CO

Fig. 7. Cross-Section of Engine and Boiler Rooms, Harrison Street Station.

ALTERNATING-CURRENT SYSTEMS.

The development of the alternating-current system in America is due largely to Mr. George Westinghouse, who, in 1885, had built at Pittsburg, Pa., an experimental plant to work out the system devised by Gaulard and Gibbs in England. The first commercial result of the Westinghouse investigations, carried on



Fig, 8. 1200 H.P. Southwark Engine and 400 K.W. Generator.

by Shallenberger, Stanley, and others, appeared in the plant installed at Buffalo, N. Y., in November, 1886. The following year, 65 plants, with a total capacity of 125,000 lights, were built, and the increase thereafter was rapid.

With a direct-current three-wire system using 230 volts between outside conductors, it is uneconomical to transmit current much farther than one and a half miles, because of the prohibitively large amount of copper necessary to keep down the loss in the feeders. The resistance of a conductor varies with the length; and as it requires the expenditure of energy to send a current over a resistance, obviously a high resistance means a large amount of energy lost in the transmission. By increasing the cross-section of the feeder, this resistance can be kept low; but the cost of the feeder would then be prohibitive. By means of the alternating-current system with static transformers, connected as shown in Fig. 9, energy can be transmitted at a much higher voltage from the station. The higher the voltage of transmission, the smaller will be the current (amperes) for a given energy (watts); therefore with the high-voltage system, a given energy can be transmitted over a much smaller wire than would be required for that same energy at a low voltage. In the transformers placed at or near the point where the current is to be used, the pressure is "stepped down" to the voltage of the lamps on the circuit.

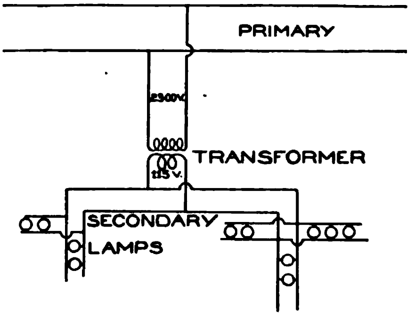


Fig. 9.

The regulation—that is, the steadiness and constancy—of the voltage of these alternating-current lines, was very much poorer than that of the direct-current system. This was largely due to the effects of self-induction, which is ever present with alternating currents. The early incandescent lamp used on the direct-current 110-volt systems was rather delicate, and had only a short life when burned on a circuit in which the pressure fluctuated very much. Consequently, it could not be used economically on the existing alternating-current lines. A 50-volt lamp could be made far more stable, and, largely because of this, the secondaries of the early transformers were wound for 50 volts. The primaries were wound for use on 1,000-volt circuits—which was then considered as high as desirable, because of the difficulties of insulating the line, the transformers, and other apparatus on which this voltage was applied. Rapid advance, however, was made in the art of insulating, and soon this primary pressure was doubled. Most of the city A. C. distributing systems now have a primary pressure of about 2,300 volts. It is interesting to note that the insulators used on the early European high-tension lines were constructed with a trough along the edge on the inner side, which was filled with oil in order to prevent current leaking over the surface of the insulator to the pin and thus to ground, by way of the cross-arm and pole, on wet days.

One of the larger of the early stations for the generation and distribution of alternating current was built in St. Louis, Mo., in 1889. The system adopted was single-phase, 1,200 volts, 60 cycles*, with a three-wire Edison system for the secondaries. These secondaries were tied together at street crossings, forming a complete network similar to that described for the direct-current system, and shown in Fig. 10. In this case the feeders of the D. C. system were replaced by the high-tension A. C. feeders and transformers, the latter being treated as part of the feeders. Pressure wires were connected to the secondaries of the transformers, and were run back to the station voltmeters to be used by the switchboard operator in regulating.

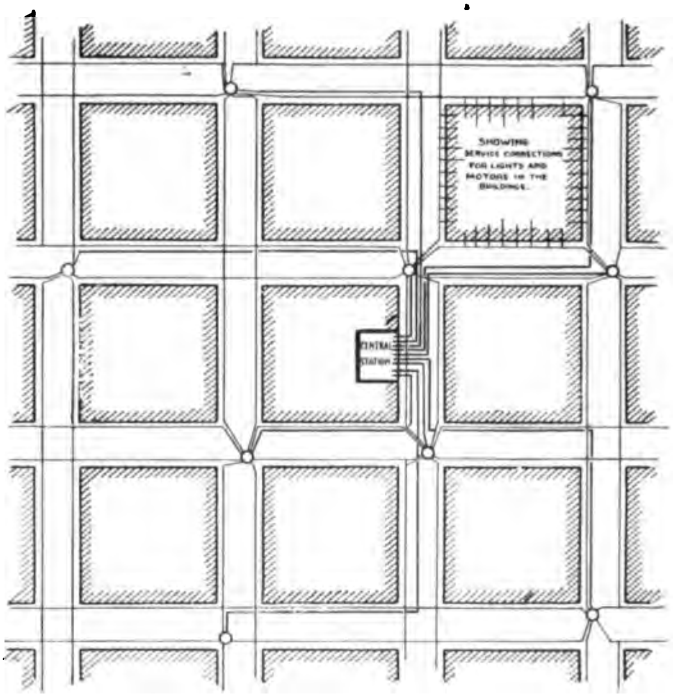

SHOWING SERVICE CONNECTIONS FOR LIGHTS AND MOTORS IN THE BUILDINGS.
CENTRAL STATION

Fig. 10.

An interesting alternating-current line was built between San Bernardino and Pomona, California, in 1891. Here a transmission pressure of 10,000 volts was used, obtained by means of connecting the 500-volt primaries of twenty transformers in series. Thus each transformer had to have insulation for a working pressure of only 500 volts, which was comparatively easy to produce.

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*NOTE. A current which alternates 120 times per second has 60 double alternations or "cycles" per second.

In 1891, the celebrated three-phase transmission line from Lauffen to Frankfort, in Germany, was operated. Originally this was intended for transmitting energy generated by water power at Lauffen, to the city of Heilbron, six miles away; but it was first used in the now famous transmission to Frankfort, a distance of 110 miles, at the time of the Frankfort Exhibition. The dynamo, built at the Oerlikon Works in Switzerland, was star-connected, and generated a star pressure of about 50 volts.

In a three-phase star-connected generator, the armature windings consist of three branches which are connected at one end to a common point. These branches are so placed on the armature core that the wave of the alternating pressure is set up in one coil a little later than is the wave of pressure set up in the coil immediately ahead of it, and a little sooner than the wave in the coil immediately back of it. These three pressures then follow each other in regular succession, the phase difference (the time between similar values of the different waves) being equal to one-third period.* The wires leading to the other ends of the three armature coils are called the "phase" wires, while the one connecting to their junction is the "neutral" wire. The pressure between a phase wire and the neutral is called the "star" pressure, while that between any two phase wires is called the "delta" pressure. This latter is 1.732 times as great as the star pressure. For greater safety in operation—principally to prevent abnormal rises in pressure between a phase wire and earth—the neutral wire is thoroughly "grounded" by being connected to a plate embedded in the moist earth.

The 50 volts pressure generated at Lauffen was "stepped up" by transformers of 8,000 volts, delta, at which pressure the current was transmitted.

DEVELOPMENT OF WATER POWERS.

After the success of polyphase transmission had been thus established, a great impetus was given to the development of water powers, and the following years found this system adopted by many companies. One of the first of these in America was built at Telluride, Colorado, in 1892. The original pressure used here was 3,000 volts, three-phase, straight from the generator. As a result of an extended series of experiments made on this line in 1896, much valuable data was obtained regarding high-tension transmission; and to-day there are many such systems, some operated at a pressure as high as 40,000 volts, which is the pressure now used at Telluride, while a few others are going still higher. The limit to-day seems to be about 60,000 volts, but even this may be increased as the art advances.

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*NOTE. A period is the fraction of a second for one complete cycle of the alternating wave.

The Sacramento-Folson line, in California, built in 1895, originally transmitted 1,000 H.P. at 11,000 volts, three-phase. The generators were wound to give a pressure of 800 volts, and this was raised in transformers to 11,000 volts.

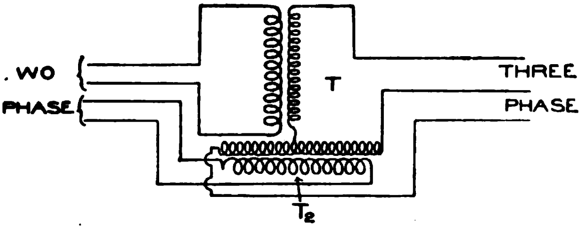
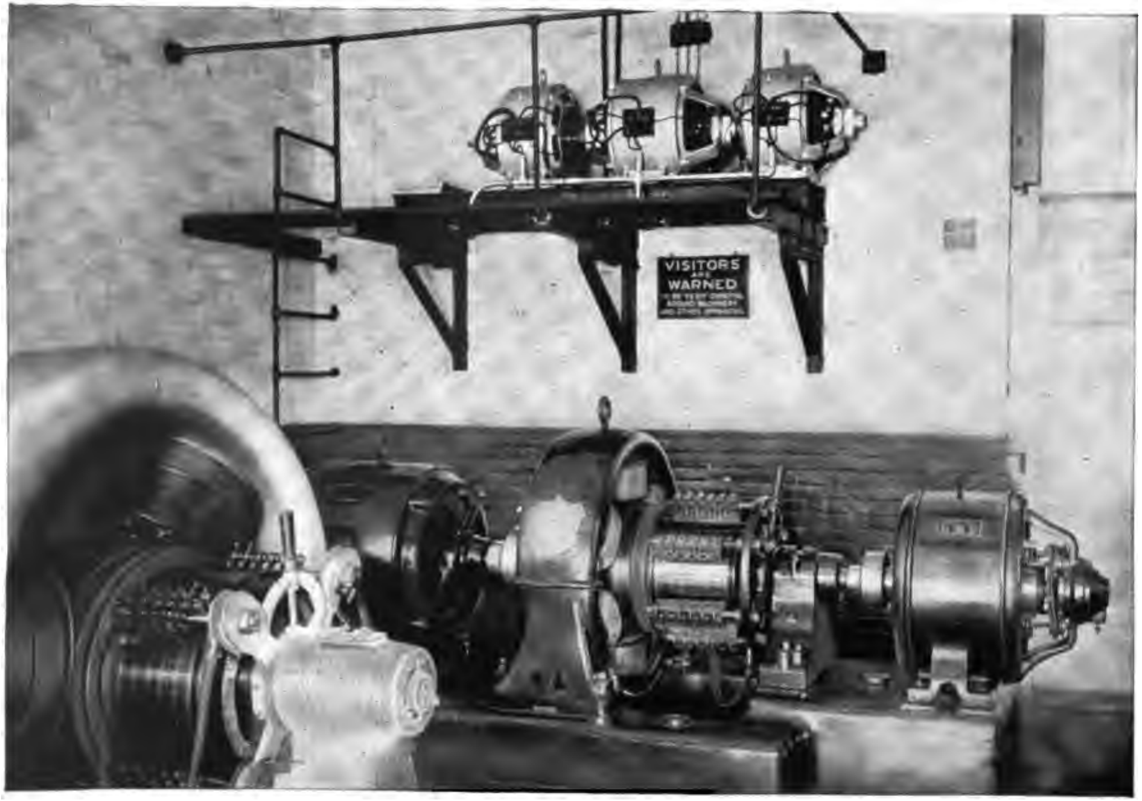


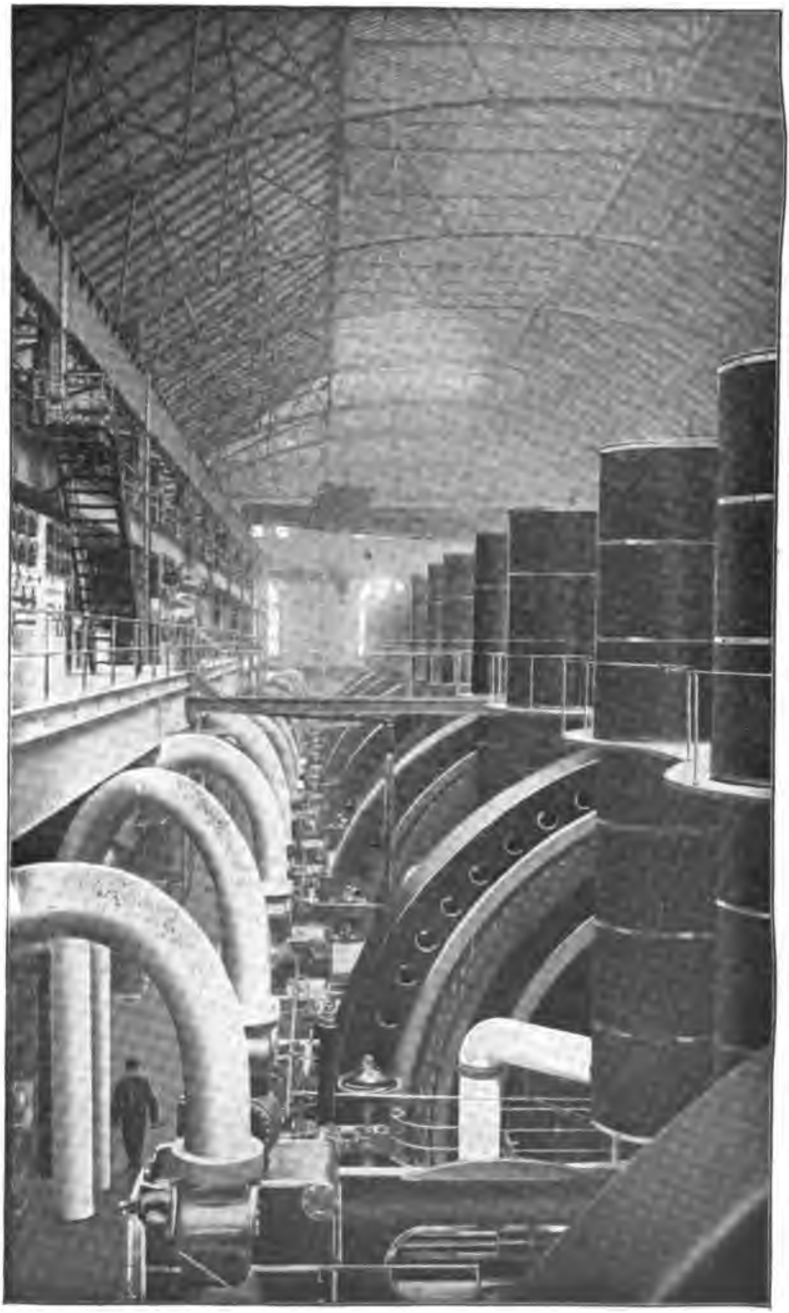
Fig. 11.

The Mechanicsville, N. Y., and the Snoqualmie Falls, Wash., plants are the most important three-phase transmission systems built in 1898. In the former, a transmission pressure of 12,000 volts, 38 cycles, was adopted; while in the latter, the generated pressure of 1,000 volts, 50 cycles, were stepped up to 25,000 volts.

Many of the polyphase stations built in the early nineties were equipped with two-phase generators. The two-phase currents were then stepped up and transformed to three-phase currents by means of a scheme of connections devised by Mr. Charles F. Scott. This connection is shown in Fig. 11. In this diagram, T and T_2 are two transformers, the primaries of which have the same number of turns and are connected to the two phases of the two-phase circuit. The secondary of T has only .866 times the turns of the secondary of T_2. By connecting one end of the secondary of T to the middle of the secondary of T_2, as shown, three-phase currents of equal pressures on each phase are obtained from these secondaries.



REGULATING BOOSTER SET
Gould Storage Battery Co.



MANHATTAN 74th ST. POWER STATION, NEW YORK.

Showing Carey's Carbonate of Magnesia Pipe Coverings. Steam Connections.

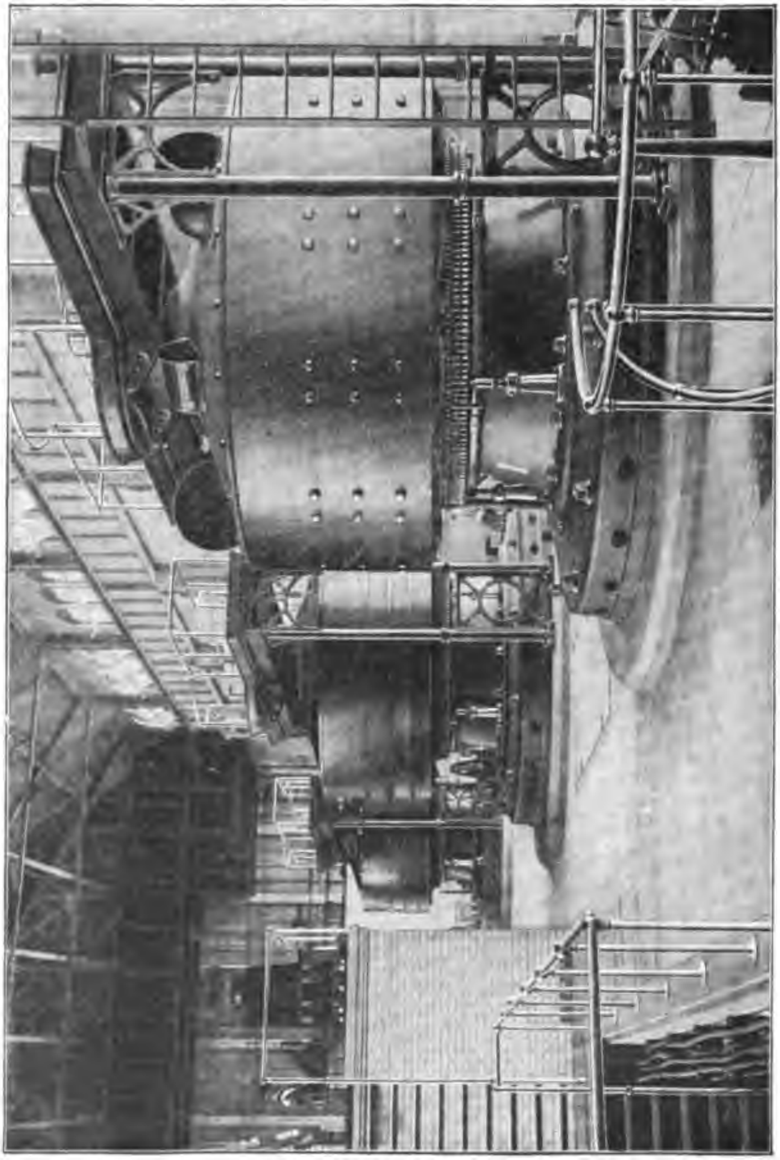


Fig. 12. Interior of Power House No. 1, at Niagara.

The best known example of this is the system at Niagara Falls, N. Y., where 25-cycle two-phase currents, generated at 2,200 volts, are transformed to three-phase currents at 22,000 volts, at which pressure the energy is transmitted to Tonawanda and to Buffalo, the latter being about twenty miles from the station. When this station was first operated, in 1896, the transmission pressure was 11,000 volts. Since that day many high-tension transmissions have sprung into existence; and the increase in voltage is keeping step with the improvement in insulators, as already noted. An interior view of Power House No. 1 at Niagara Falls is shown in Fig. 12.

FUNCTION OF THE STORAGE BATTERY.

While these important developments in cross-country transmission were under way, the engineers of the urban stations also had a few problems to solve. The convenience and other desirable features of the use of electric light and power were now being widely appreciated, especially when the cost of the lamps was reduced; and electric motors also were being used more liberally, in sizes from one-fourth horse-power to 300 H.P. and larger. This meant a big increase in the load on the station, as well as in the size of the district to be served. How to meet this increase economically, required an intelligent study of the problems of current distribution. As already noted, the distance over which it is economical to transmit current at a low voltage is limited; and, when the area to be served exceeds this limit, recourse must be had to more stations or to a higher distribution pressure. A study of the load curve of an average central station in a large city (Fig. 13) shows that the feeders are carrying their heavy current for but a short time each day. During all the remainder of the day, then,

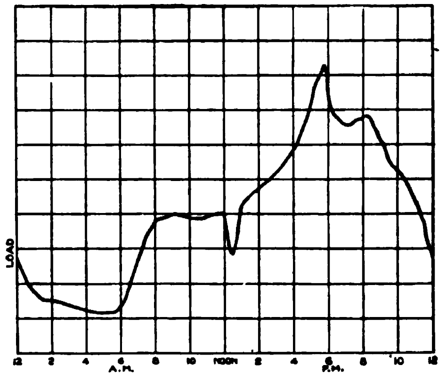


Fig. 13.

the current in these feeders is comparatively small; also, much of the generating capacity of the station is idle, representing just so much investment inactive and earning no returns. If now, during the period of light load, a current, additional to the regular load, can be sent over these feeders, and if this current can be stored in some way in a location within but near to the economical limit, so that it can be used at the period of heavy load, this storage substation will in turn become a point of distribution from which current can be sent out as far again as the economical limit. Here is where the storage battery filled the want. In 1894 we find storage-battery substations installed in Boston and New York, and soon after companies in other cities adopted them. In Boston, a number of battery substations were installed in the nearer outlying districts, all of them being connected with one another and with the steam station. The batteries are charged during the hours of light load by means of boosters, which form part of the substation equipment. Their usefulness, however, is not by any means limited to outlying districts. As an auxiliary to a generating station, it is considered good practice from the standpoint of economy to install a storage battery if the peak of the load does not exceed two and one-half hours. As a safeguard against interruption of service, and as a help in maintaining a uniform pressure on the system, they have been found almost invaluable.

CONSOLIDATION OF PLANTS.

The next step in the development was one of consolidation. Many cities had been liberal in granting franchises to lighting companies, and as a result there were built within the same city many systems of various excellence and stability. To the engineers of the consolidated company was then presented the problem of unifying the systems; but the changes to the new system had to be made without sacrificing the value of the investment represented by the generating apparatus and lines of the existing stations. Such a change, naturally, was made step by step, and thus required several years. In addition to providing for the existing load, the new system had to be designed for the future, and the probable development in the line of various classes of electrical apparatus had to be considered.

In our larger American cities, the load conditions can be divided into two general classes—one, in which a large load is concentrated over a comparatively limited area, which is the downtown or business district; and the other, the residence district, where the load is widely scattered over a large area. In the downtown district, nearly 30 per cent of the load goes to power users; therefore the system had to be adapted to all classes of motor service, as well as for lighting. For this service in such a district, the Edison direct-current three-wire system is certainly the most satisfactory, and this system has been pretty generally adopted. It permits the use of storage batteries; requires less copper than does the alternating-current system, because in it there is no loss due to inductance; gives better regulation; and is far better for general all-around power service.

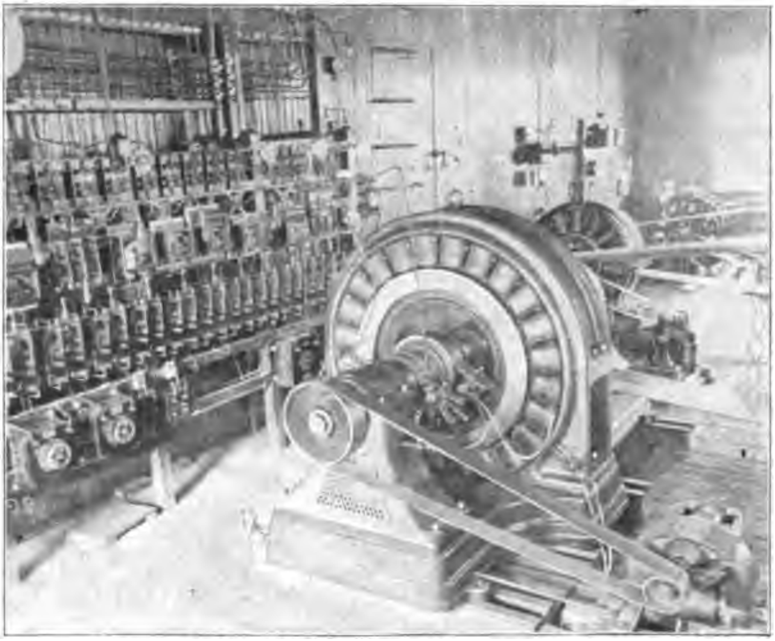


Fig. 14. Early Alternating-Current Station.

To consolidate several systems of this class was a simple matter. It required merely that the separate networks of mains be tied together, and a uniform pressure kept on the system by each station feeding into it. In the outlying districts, however, the problem was more complicated. Because of the scattered load, most of the systems feeding these districts used alternating current. But there was a wide divergence in regard to frequency and voltage. Some of the lines were 1,000-volt; others, 2,000-volt. Some used a frequency of 125 cycles; others, 133 or even 144 cycles. The secondary pressure ranged from 104 to 125 volts, while some of the earlier systems still maintained a secondary pressure of 50 volts. A few of the later stations had 2,000-volt lines, with a frequency of 60 cycles; and there were also polyphase (generally two-phase) lines for serving a motor load. A view of an early alternating-current station is given in Fig. 14.

High-Voltage Polyphase Systems. This conglomerate mass, then, had to be unified. A careful study of various systems showed the four-wire three-phase system, with a frequency of 50 to 60 cycles, to be the best suited to the distribution of such a load; and this system is being freely adopted. Good examples of it are found in Chicago, Milwaukee, St. Paul, and Cincinnati. The generator for this system is star-wound, with the neutral grounded, as already explained. The voltage at which this system is generally operated is 4,000 between phase wires. This gives a pressure of approximately 2,300 volts between any phase wire and the neutral; and the single-phase lighting feeders are switched on to this 2,300-volt

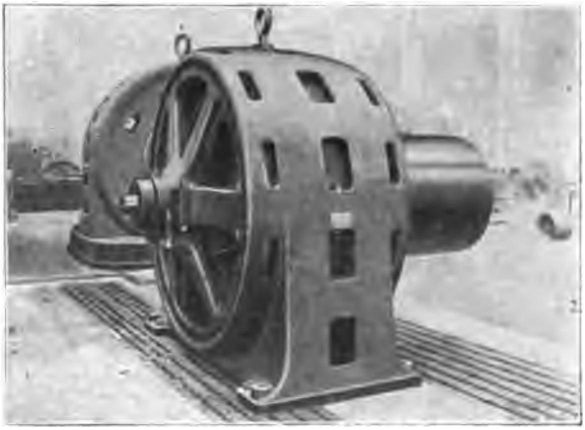


Fig 15. Polyphase Induction Motor.

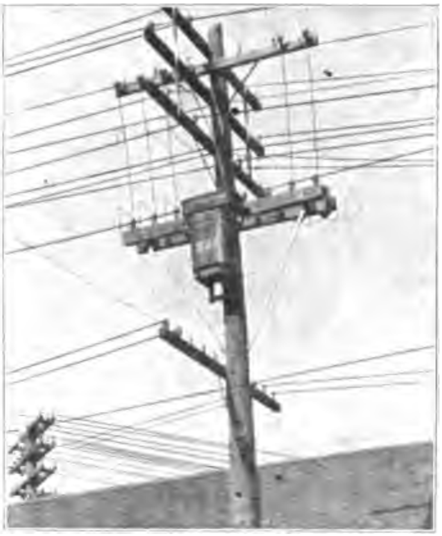


Fig. 16.

connection. The various feeders are connected each to one of the phases and the neutral, so that the three phases are approximately balanced. For a power load, then, connection is made to all three phases, and the motor is usually of the polyphase induction type, of which one is shown in Fig. 15. Where the capacity of the motor is very small—under 3 H.P.—the single-phase type of induction motor, equipped with some special starting device, is often used. Step-down of the voltage to the service pressure is, of course, accomplished by means of the ordinary 2,300-volt static transformers.

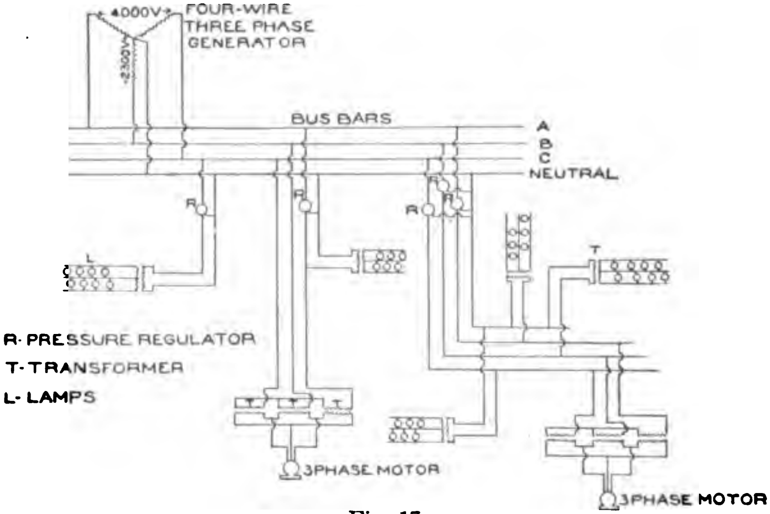


Fig. 17.

In Fig. 16 is seen a 150-light (7.5-K.W.) transformer on a pole. The two wires coming down at the right are the 2,300-volt primaries; while the three-wire secondaries, of 115 volts per side, are brought up at the left. A diagram of a four-wire three-phase distribution is shown in Fig. 17; and in Fig. 18 is seen a switchboard installed for such a system.

When the transmission distance is great, this three-phase pressure can be raised to any desired amount, and then stepped down again at the substation, the local distribution again being done on 2,300-volt single-phase feeders with a pressure of 4,000 volts between phase wires. In some cities, a two-phase system was adopted; while others, again, used the three-wire three-phase system (in which a neutral conductor is not used and all load is connected between phase wires). Brooklyn has a two-phase 2,300-volt 60-cycle system in the residence section; Philadelphia also, though in the latter city the current is generated at 5,500 volts and stepped down to 2,300 volts alternating-current distribution.

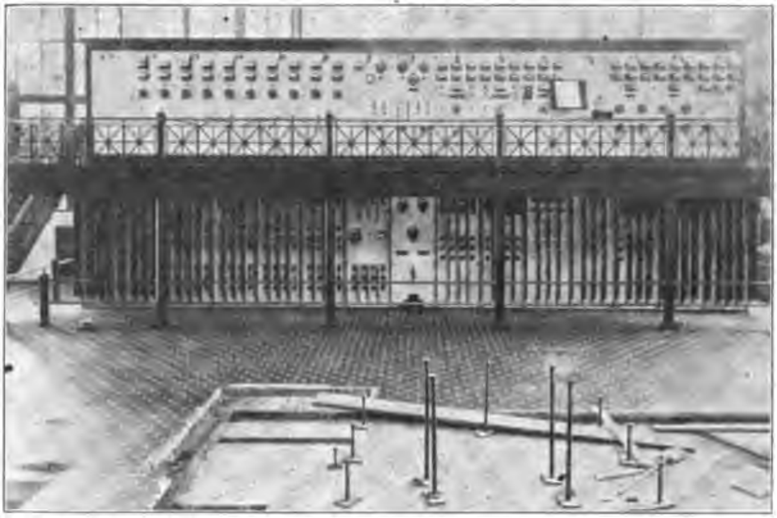


Fig. 18. Switchboard of 4-Wire 3-Phase Distribution System.

A 500-volt two-phase generator is shown in Fig. 19. For higher voltages the revolving-field type is used, thus avoiding collector rings and brushes for the high-voltage current. At the South Boston station of the Boston Electric Light Company (now part of the Boston Edison Illuminating Company), the generators are wound for 2,300-volt three-phase 60-cycle currents.

In the direct-current districts, the load often increased very heavily in sections somewhat remote from the generating or the distributing center; and then it became a question of more stations, more copper, or some other additional means of transmission. To provide enough copper for satisfactory transmission and regulation, would bankrupt a company. To build and operate a new generating station in each section of heavy load, would be equally ruinous. Consequently recourse is had to other means of transmission. The success and the comparative copper economy of polyphase transmission lines, already mentioned, showed that system to be the proper one to adopt; and the three-phase system was chosen as the means to transmit current to substations located at or near the electrical center of the load. Such a transmission system, from a large alternating-current station in preference to several direct-current generating stations, is considered good engineering whenever the total energy generated is large as compared with that used at any one locality. The voltage determined upon depended to some extent on the local conditions, but more largely on the efficacy of the insulation of underground cables, since in the cities all lines must be below the surface. In the early days of underground cables, 5,000 volts was thought very high pressure; to-day 25,000 volts is not considered excessive; and a recent article in the *Electrical Age* stated that an underground cable system will soon be installed, to be operated at 30,000 volts. The insulating material used in these high-tension cables consists of paper treated with a resinous compound, the thickness in the 30,000-volt cable

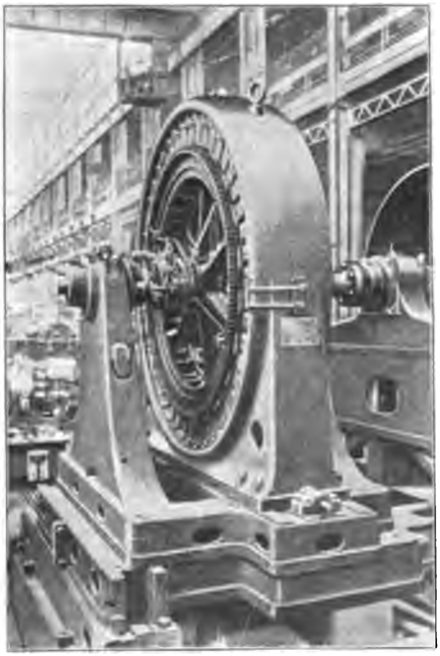


Fig. 19. 500-Volt 2-Phase Generator.

being about one-half inch. Over this is a lead sheath about $\frac{1}{8}$-inch thick, to protect the cable against moisture and mechanical injury. These cables are drawn into ducts laid below the surface in the streets, as shown in Fig. 2.

One of the earliest instances of the use of a three-phase transmission to a substation, for conversion to direct current of an Edison system, was in Chicago, where, in 1897, a 250-K.W. inverse rotary converter, which converted direct current of 250 volts to three-phase 25-cycle currents was installed at the Harrison Street station. By means of step-up transformers, this pressure was raised to 2,250 volts, the pressure of the transmission. In the substation on Wabash Avenue, near Twenty-seventh Street, this voltage was stepped down again; and, after passing through the rotary converters, the current was fed into the direct-current system at 115 volts, one rotary being connected to each side of the Edison system. Such was the humble beginning of the very extensive system of high-tension transmission lines and substations, which, at quadruple the initial voltage, is now in operation in Chicago.

In the same year there was installed in Brooklyn, N. Y., a similar transmission system with a rotary converter substation. Here the current was generated at 6,600 volts, 25 cycles, three-phase, at the Union station, a similar system to that operated by the New York Edison Company. In the magnificent Waterside station of this latter company, there are at present eleven 5,500-H.P. vertical engines, each driving a 4,500-K.W. three-phase 25-cycle 6,600-volt alternator. A 5,000-K.W. Curtis turbo-generator is being installed, and there is room for four more. This will make a total rated capacity of 75,000 K.W., all power being generated as alternating current for transmission to rotary converter substations, from which it will feed into the Edison three-wire direct-current system. In the splendid new Fisk Street station in Chicago, 9,000-volt 25-cycle three-phase current only is generated, all by Curtis turbo-generators. Fig. 20 shows a Westinghouse-Parsons unit of 5,000 K.W. capacity.

In Philadelphia, the 5,500-volt two-phase 60-cycle system, already referred to, is used for transmission to rotary converter substations, as well as for the alternating-current distribution, Fig. 21 shows a row of rotary converters of a substation located in

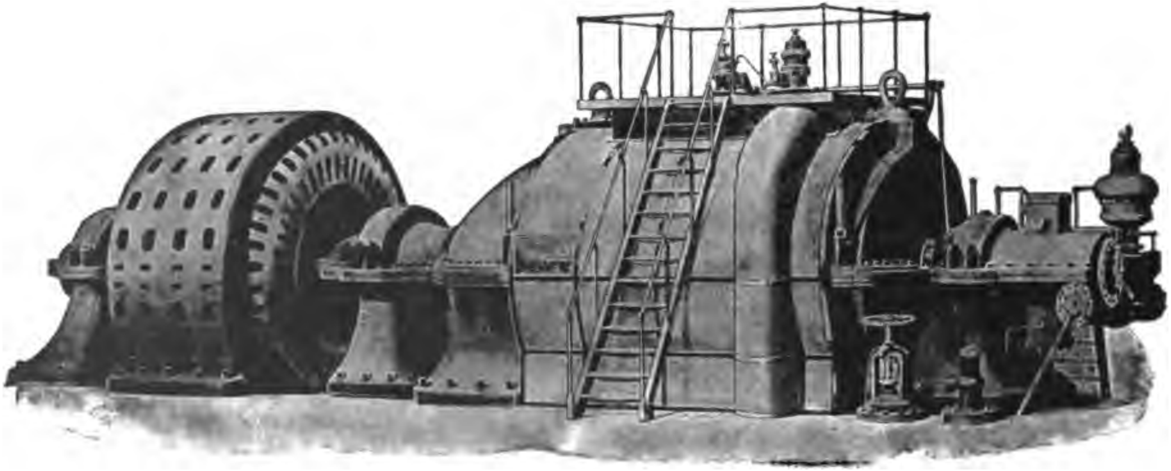


Fig. 20. WESTINGHOUSE-PARSONS 5,000 K. W. TURBINE GENERATOR.
For the Pennsylvania Railroad Tunnel, New York.

the basement of a sky-scraper in the heart of the business district of Chicago.

Where the load connected to transmission lines consists solely of substation converting apparatus, a low frequency is desirable because of the accompanying low inductive and capacity reactance of the lines, and also because of the slower speed of the synchronous motors and rotary converters which is had for a given number of field poles with a lower frequency. The higher the frequency, the greater the number of poles required, or the greater the speed. Because of the necessary number of commutator bars required between the brushes of a D. C. machine, and therefore also on a rotary converter, the distance between the centers of the pole pieces (that is, the pole "pitch") cannot be less than a certain fixed limit; and, therefore, for a given speed, the lower frequency allows a far simpler and cheaper construction. The higher-frequency machines are also more liable to "hunt" especially when the load varies considerably. Furthermore, double-current generators having a commutator connected to the armature windings for direct current, and also having connections to collector rings from which alternating current is taken off, are not practicable for frequencies much above 25 cycles. These double current generators, producing both direct and alternating current at the same time, form a very valu-

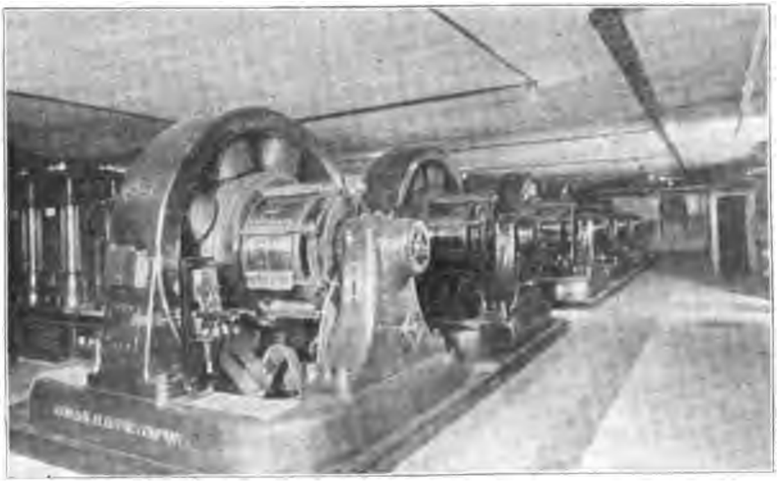


Fig. 21. Rotary Converters in Basement of Office Building.

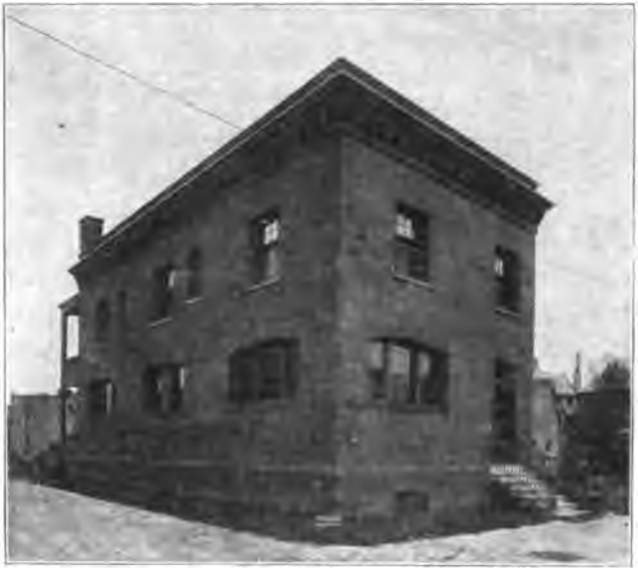


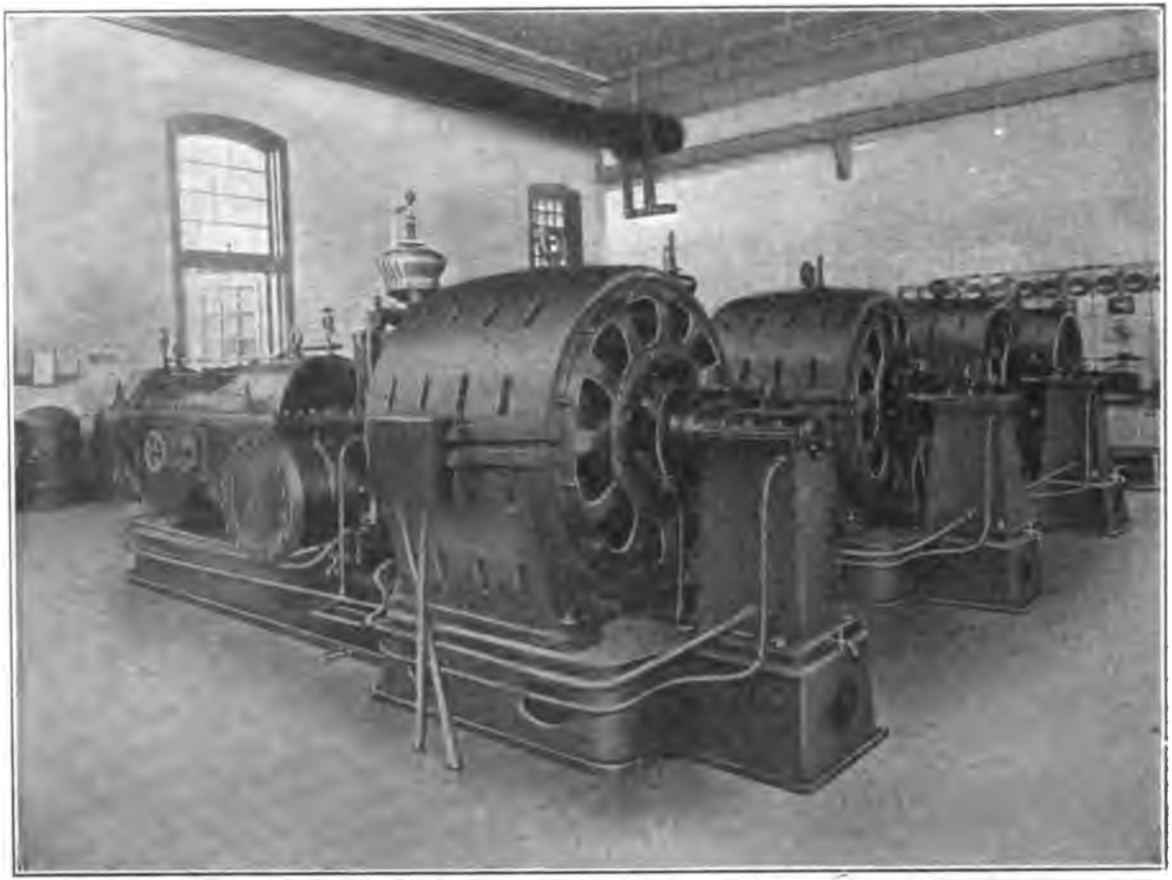
Fig. 22. Modern Light and Power Substation.

able element in a large station in which both these currents are generated, the direct current for general distribution, and the alternating current for transmission to substations. A frequency of 25 cycles is therefore generally accepted as the most desirable for straight transmission; but the alternations are noticeable on incandescent lamps at even 30 cycles, while arc lamps will not burn at all satisfactorily on frequencies of less than 40 cycles. Because of these facts, the alternating distribution, as distinguished from transmission to substations, is effected by 60-cycle current. The 25-cycle transmission current is then converted to current of 60 cycles per second by means of motor generators or straight frequency-changer sets.

In Europe, a compromise frequency of 42 and sometimes 50 cycles is common; and current is transmitted and distributed at this frequency, thus requiring only voltage transformers and no frequency changers. A few 25-cycle systems have been installed in Germany. For converting to direct current, motor generators are used more freely than are rotary converters. European transmission lines of 10,000 volts three-phase are not uncommon.

With the advent of polyphase transmission in connection with lighting and power systems, the old 500-volt power lines are gradually being abandoned, the power load being connected to the 230-volt circuit of the Edison three-wire system, or, if in the outlying districts, to the polyphase 60-cycle lines. Series arcs have already been largely displaced by constant-potential arc lamps. What this new system meant to the neighborhood in which the old stations were located, will be appreciated when one remembers the noise and dirt and smoke of these old stations, and then views Fig. 22, a substation set in the rear of a lot in a fine residence section.

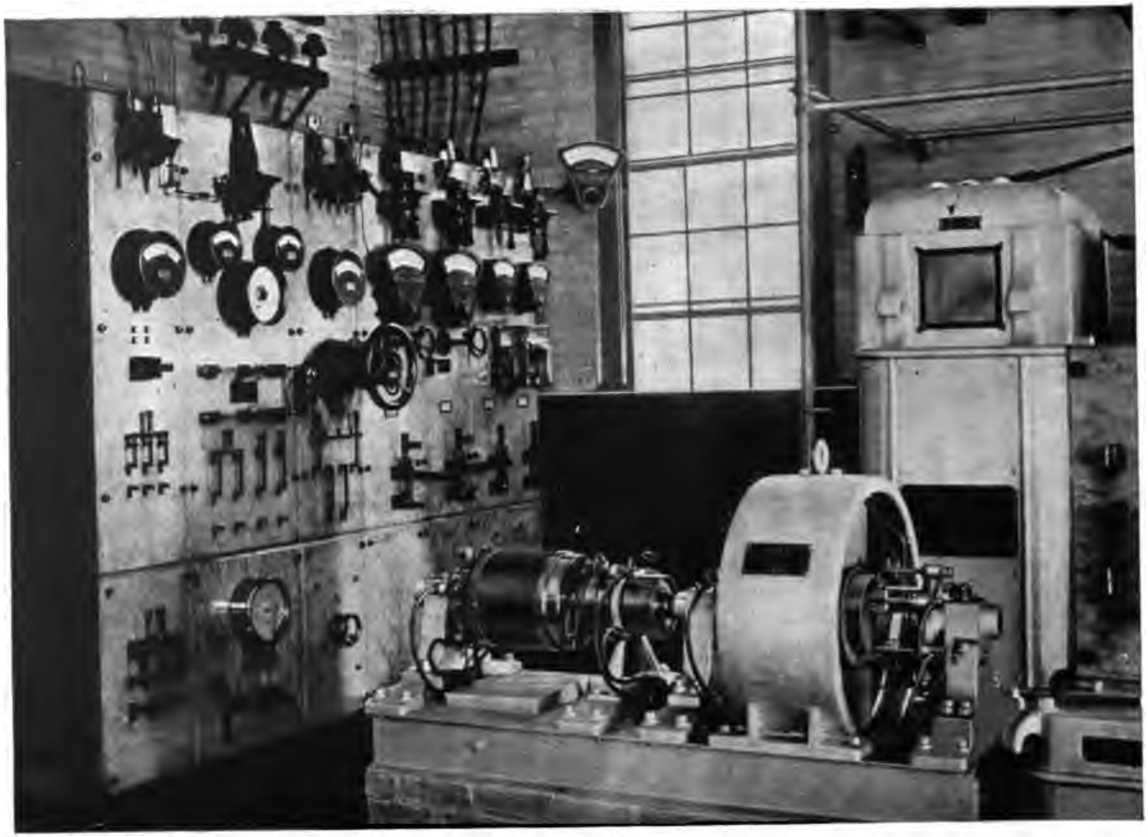
We have seen, then, how the high-voltage polyphase system has been evolved out of, and has unified, the mixed systems which were brought under one head during the era of consolidation. A study of some of the newest installations leads to the thought that perfection of system has almost been reached, and that further progress will be rather along the line of higher efficiency of apparatus at both ends of the system. When the true electrical era has arrived, when houses no longer have need of chimneys and all operations are performed electrically, then new problems will arise. How they will be met, none can now say; but they will be met successfully. Another Edison—many of them, perhaps—will arise; and then our splendid systems of to-day may ultimately be supplanted by one of which the most imaginative dreamer as yet has seen no vision.



FOUR 400 K.W. TURBINE GENERATING UNITS.

Westinghouse Electric and Manufacturing Co.

OF MICH.



ROTARY RECTIFIER AND SWITCHBOARD PANELS
Gould Storage Battery Co.

A MODERN CENTRAL STATION DESIGN.*

The design of most of the central stations in this country can hardly be said to be ideal; first, on account of the handicaps and limitations imposed by the location and environment of the selected site; secondly, because usually the cost of the land to be built upon renders it imperative that the area covered be made as small as possible.

In selecting the site for a large power station, three main problems confront the engineer—first, a satisfactory location with a low valuation must be found which is reasonably near to the bulk of the business; secondly, the location must be so situated that the fuel can be brought to it with the least expense for freight and handling; that is, it should be somewhere on a main ship-channel below all drawbridges with ample depth of water and docking facilities for coal-carrying vessels up to seven or eight thousand tons burden. Also there should be ample ground adjacent to both the dock and the proposed station site to permit the storing of at least six months' supply of fuel, and so situated that the minimum amount of coal-handling and conveying machinery is required. Thirdly, an unlimited supply of suitable cooling water must be provided for the condensers; this should be such that the temperature will not be excessive during the summer time. The water should be free from sewage, seaweed, and other debris; and the proposed location for the station should be such that the distance the water has to be lifted from the level of the supply to the top of the condensers is as small as possible; and the length of pipes or tunnels employed to take the water from the supply to the farthest condenser is as short as possible.

The location of the L Street station of the Boston Edison Company fulfills these conditions admirably. The ground consists of two city lots of about 25 acres, two-thirds of which is solid ground, and is situated at the corner of L and East First streets, South Boston.

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* Prepared by I. E. Moultrop and presented at the 193d meeting of the American Institute of Electrical Engineers, New York, January 27, 1905. Reprinted by permission.

Measured by an air-line it is about two miles from the center of the business section of Boston. It has a water front of 815 feet on the so-called "Reserved Channel," is one-half mile from the main ship-channel of Boston Harbor, and is so located that no bridges will ever be built between it and the main ship-channel.

The solid ground consists principally of gravel with a bed of clay underneath so that the heaviest construction called for in the building of the station can be carried on ordinary footings without the use of piles. The area of the solid ground is more than double that required for the ultimate size of the station under consideration, consequently there is ample room for the storage of fuel close to the boiler-house.

Before taking up in detail the design of the station, a brief description of the company's territory will be given. The Boston Edison Company's system supplies electricity to a heavily-loaded business section of the city, which covers a comparatively small area located within a mile of the water-front. This business is supplied by a direct-current station on the water front having 10,500 K.W. of machinery, with room to increase the capacity to 14,500 K.W. Surrounding this business section is a city residential district where the load is considerable, although much lighter, than in the business part. Here the customer receives direct current from sub-stations supplied, through motor-generator sets, from the existing alternating-current station of 9,000 K.W. capacity, located on the L Street property. The output of these sub-stations being direct current, they are, with one exception, equipped with storage batteries.

Many of the business people of Boston live in the surrounding cities and towns. Up to a few years ago most of these suburban places had their own local electric-light companies, usually operating small uneconomical steam-generating stations equipped with more or less obsolete forms of machinery.

Within the last two years the Boston Edison Company have purchased the property of many of these local companies, and in most instances are changing the stations to modern alternating-current sub-stations, making a suburban business which extends in various directions from 12 to 30 miles outside of the city.

This large increase in suburban territory together with the rapidly-growing city business called for an immediate enlargement to the alternating-current station which was already loaded to its full capacity. A new station was therefore planned with an ultimate capacity of 60,000 K.W. to be built on the L Street property alongside the existing station. The first installation of 10,000 K.W. is just being completed. The position of the existing station on the property was fortunately such that it was no handicap in the location and arrangement of the new station. As a matter of fact, the old station naturally merges into and becomes a part of the new station, and had it not existed it is doubtful if any change would have been made in the design of the latter.

The value of the real estate is very small and will doubtless so continue for many years to come. Therefore the station buildings could spread out over the land as much as desired, and no attempt was made to build additional stories for the sake of saving ground area. Under these conditions, it is cheaper to spread out the buildings on the ground than to carry them up in the air to an equivalent area, and liberal room for and around the apparatus facilitates the operating, cheapens the cost of making repairs, and renders it easy to keep the stations clean.

The shape of the property was such as to make it desirable to erect the buildings with the ends toward the water front, which naturally brought the building of that end of the station first.

The turbine-room will be 650 feet long, 68 feet wide, 56.5 feet high, and without a basement. It has no side windows. A liberal monitor with glass sides and roof gives a better distribution of daylight than do side windows and in connection with windows in the end walls provides good ventilation.

The boiler-house will be 640 feet long, 149.5 feet wide and of the same height as the turbine-room. The arrangement of the boilers practically divides this building into seven fire-rooms. The lighting and ventilating is done from the roof similarly to the turbine-room.

The switch-house will be 605 feet long, 30 feet wide, and several stories high. The buildings for the installation of 60,000 kilowatts of machinery cover about 160,000 square feet, which is equivalent to about 2.67 square feet per K.W.

The ends of the buildings facing the water have been made the front of the station; with an entrance through offices located in the front end of the switch-house. The buildings are set back 136 feet from the sea-wall, the intervening space covered with a fine lawn and planted with shrubbery. Through the center of this lawn a paved driveway leads from the ornamental entrance gates on L Street to the office entrance, making a well finished and attractive environment in keeping with the interior.

In designing this station the grouping of the apparatus has been given special attention and care has been taken so to arrange them that they naturally come under the charge of the class of operators best fitted to care for them.

The turbine-room has received all of the machinery in the station; even the boiler feed-pumps usually considered an adjunct of the boiler-house are treated as part of the turbine auxiliaries, and are placed in charge of the turbine operators. The boiler-house contains only the boilers with the necessary piping, etc., so that the work in this room is to burn coal properly and maintain the steam pressure.

All of the electrical apparatus has been grouped together and installed in a separate building adjoining the turbine-room, isolated from the noise and dirt of the latter and free from liability of damage by accidents to any of the turbine-room machinery.

The electrical operating, a matter of brain work, is done under as favorable conditions as is found in any office building, with no duplication of apparatus, and the operators cannot be disturbed by anything going on in the turbine-room. Escaping steam can neither damage the apparatus nor interfere with the work of the operators, while they can oversee any of the generating rooms by stepping through doors in the side walls on to observation galleries.

To add to the architectural appearance of the interior of the turbine-room, and also to facilitate the work of keeping the room neat and clean, it is finished with tile and enameled brick. The floor is tiled in dark red with black borders arranged in the form of a simple design to relieve the monotony of one color. The walls have a wainscot of two-colored green tile about ten feet high, and above they are paneled with a light-colored tile and enameled brick. The crane track is concealed by the wall finish. This room is divided into three parts by permanent division-walls in which are large doors at the floor level, and large windows above, all equipped for quick closing. Ordinarily these will be opened, giving practically one long room, but in case of a serious accident in any room the openings can be quickly closed, isolating the trouble and leaving the other rooms free to operate without any interruption. The boiler-room has walls finished in tile similar to the turbine-room, but the floor is not tiled. The result is that these rooms are ornamental in character and are easily kept clean, while at the same time the cost of the decoration is quite moderate. Before the finish was determined upon, cost estimates were made on the various possible methods of satisfactorily finishing the rooms, including the up-keep for an extended period of years, and the finish employed was found to be the cheapest that could be adopted, being even less expensive than painting.

The exterior of the station buildings is simple and massive in character. Cut granite underpinning is used and the prominent walls are faced with a dark paving brick trimmed with terra-cotta.

The apparatus is installed on the unit system. In the turbine-room all the auxiliaries required for a generating unit are grouped around that unit and are generally of sufficient capacity to serve that unit alone. The boilers necessary to supply the generating unit are in one row directly behind the turbine. In this way each generating unit is a small central station in itself. Practically no cross-connections are installed between the various units except that between each pair of units. The steam mains are joined by a small-sized tie so that a generating unit can be run temporarily from the boilers of its mate, should an emergency require. In this way a very simple piping system is sufficient, reducing the cost of installation and maintenance, and simplifying the manipulation of the station under emergencies when the engineer has to think quickly, and when he must be sure that the manipulations are made rapidly and correctly. The duplication of auxiliaries is eliminated, and should a generating unit be put out of commission by the failure of any one of its essential parts, it is intended that the entire unit will be shut down and another one started in its place.

Before determining upon the apparatus to be installed in the station, careful consideration was given to the respective merits of turbines and reciprocating engines as prime movers. The advantages of the turbine over the engine in first cost, the lesser amount of help required to operate, the ability to use condensed steam with safety for feed in the boilers, together with the fact that the apparatus takes very much less room, decided the question in favor of the turbine. These considerations were held to justify the decision without regard to the water consumption, and the decision will be considered wise even though the water consumption proves to be no better than that of a good engine, although it is expected to be better. Another important feature is the ability to start an idle unit quickly. The earlier turbines were open to improvement in this respect, but the later machines have been safely started and brought up to full load with remarkable speed.

The turbines used in the first installation are of the Curtis type with a rated capacity of 5,000 kilowatts on a conservative temperature rise in the generator. They are four-stage machines with surface condensers built in their bases and are equipped with mechanical brakes for bringing the machine to rest for an emergency stop. In these features they are the first machines of their kind to be installed. The base condenser was adopted because it will give a somewhat better vacuum in the turbine, which is an important consideration in turbine work. It also considerably reduces the floor space required for the installation, somewhat simplifies the piping, and makes possible a more symmetrical and pleasing grouping of the machinery. Its disadvantage is that it increases the height of the turbine a few feet, which is, however, of little moment. Its first cost is somewhat more than an independent condenser, which may be partly balanced by the saving in piping; and it requires special arrangement for filling the condenser tubes with water when the turbine is to be non-condensing.

The brake is very useful for emergency shut-downs, because the turbine will run for some hours with no load and no field, while with the brake it is possible to bring the machine to rest in about five minutes. It also facilitates the overhauling of the step bearing by sustaining the weight of the rotating parts.

The generator is a three-phase alternator, Y-connected, 60-cycle machine, generating at 6,900 volts. This number of cycles was determined upon because the bulk of the alternating-current business is lighting, and also for the reason that the existing alternating-current apparatus has the same number of cycles.

The auxiliaries for each turbine consist of a circulating-pump, a wet and a dry vacuum-pump, a step-pump, a hydraulic-accumulator, and the boiler feed-pump for the group of boilers connected to the turbine. All these machines are steam driven with the exception of the wet vacuum-pump which is motor driven because its speed is too high to be conveniently handled by an engine. Careful consideration was given to the subject of steam- versus electrically-driven auxiliaries, and steam was determined upon because it gives better station economy. All the exhaust steam from the auxiliaries is carried to the feed-water heater and is condensed in heating the boiler-feed. The condensation is then discharged to the sewer as it contains too much cylinder oil to warrant trying to purify it. As all the exhaust from the auxiliaries can be condensed in heating the feed-water, the greatest possible use is made of the heat originally put into this water in the boilers, for practically all that is not taken up in the form of work in the engine cylinder is returned to the boiler in the feed. Moreover the first cost of steam-driven auxiliaries is less than the electric drives, and speed regulation over wide ranges is much more easily accomplished.

The circulating water-pump consists of a centrifugal-pump driven by a simple high-speed engine with a throttle governor. The quantity of water to be handled is very great, and the head very low, so that a centrifugal-pump is well adapted for this duty. It also makes a very much smaller machine than a piston-pump, is much less expensive, and at the same time it is very simple and requires almost no attention.

The distinctive feature of the dry vacuum-pump is that the air-cylinder is placed at a right angle to the steam-cylinder, thus giving a better turning moment on the crank, and it takes less room. The air end is built single stage, and will maintain a vacuum on a closed tank within one-half inch of absolute. The steam end is throttle governed to permit of speed variations while running. The wet vacuum-pump consists of a two-stage centrifugal-pump, motor driven. This pump will maintain a vacuum in the condenser equal to that of the dry vacuum-pump without the use of either suction- or discharge-valves; thus requiring a minimum amount of repairs and almost no operating attention. The boiler feed-pump is an ordinary duplex, center-packed plunger-pump, selected because it is easier and quicker to repack, and a casual inspection will show if there be leakage from the plungers.

The step on the turbine is lubricated by water instead of oil, because the water is as good a lubricant for this purpose, is cheaper, and the lubricating system simpler. The water is forced into the step under a pressure of about 1,000 lbs. by a steam pump of similar design to the boiler feed-pump. As even a momentary stoppage of the water supply to the step would result in damage to the bearings, a motor-driven triplex-pump, which can be started much quicker than a steam-pump, is installed as a relay to the main step-pump. To obviate fluctuations in the pressure due to the pump's reversing its stroke, a weighted hydraulic accumulator is used. This is made of sufficient capacity to keep the step supplied with water for ten minutes, thus giving time either to shut down the turbine by means of the brake or to put the relay-pump in service, should the steam-pump fail.

The condensing apparatus is designed to condense 153,000 lbs. of steam per hour and maintain a 28-inch vacuum in the condenser, with the cooling water at summer temperature of 70 degrees Fahrenheit. The same apparatus under winter conditions and when the heaviest loads occur on the station, will give a vacuum within about three-quarters of an inch of the barometer.

The cooling water is conveyed to the pumps by brick tunnels running under the center of the turbine-room, at such grade that they are always flooded, and constructed within the building so that the machinery can be installed above them. For additional insurance, two tunnels are provided for the incoming water, each supplying one-half the station. The notable feature of this system is the intake construction at the sea wall. Racks and screens, provided to keep out all floating material, are so installed that they require very little cleaning, and the screens are arranged to be easily removed and cleaned without permitting debris to pass into the tunnels. Where the tunnels join the screen chamber, heavy timber gates are provided so that the tunnels may be pumped dry for inspection of repairs. The water-front construction is of concrete with a wing-dam so designed that, while the warm discharge-water empties into the harbor alongside of the incoming tunnels, thus simplifying the construction, at the same time the latter tunnels get the coldest water available, without danger of taking any of the warm discharge-water.

The rows of boilers are placed in pairs alternately face to face and back to back, with a chimney for each pair midway of the row and between them. Thus six chimneys in all are required, each being 230 feet high above the level of the grates, or sufficient to dispense with forced draft. Building the chimneys between the rows of boilers, considerably increases the ground area of the boiler-house, but the additional space is very useful for work-room, toilet-rooms, etc. The boilers are elevated from the ground to provide liberal space beneath for the ash handling. Large brick chambers immediately below the boiler furnaces collect the ashes, and discharge through valves in their bottoms into carts or cars on the ground floor. Other distinctive features of the boiler-room are the provisions for bringing air to the furnaces, the location of the piping mains, and the small capacity of the coal-bunkers.

The ash-room has a free circulation of air at all times through openings in the exterior walls which are without doors and are provided with grills. In the front wall of each ash-chamber, close to the fire-room floor, are openings equipped with dampers admitting air directly to the ash-pits and maintaining an adequate supply to the furnaces, while permitting the windows and doors to be closed, during extreme weather conditions.

A portion of the basement under each two rows of boilers is separated from the ash-room by partitions forming the pipe-room. Immediately under each row of boilers in this pipe-room are installed all the various pipe-mains which connect with them, and only branch pipes to each battery of boilers are taken into the fire-room. This puts the most of the boiler-room piping into a warm, clean room by itself where it is accessible, free from cold drafts which would tend to start leaks, and where it can be carried upon substantial supports.

The grouping of boilers and turbines which has been adopted, gives a smaller amount of piping than would be the case were the boilers placed in the usual manner in two rows, parallel to the turbine-room, and makes a very short smoke-flue with a minimum amount of reduction in the draft.

Supplying each row of boilers is a line of coal-bunkers built in monitors above the roof. As there is practically no piping on top of the boilers, little space is needed above them, and building the coal-bunkers in monitors enables the boiler-house to be made quite low, saving considerable expense in the cost of the structure, and also in heating only a small waste space above the boilers. As there is always a large amount of coal stored alongside the station, the capacity of the bunkers is made small, being sufficient to last during the time of making routine repairs in the coal-conveying system. This reduces the cost of the building very materially. The boilers are equipped with the attached type of superheaters and automatic stokers. They are higher by two rows of tubes than is the usual practice, which provides for additional storage of hot water, and in such form that it will also serve as additional heating surface.

The amount of superheating, 150° Fahrenheit, was made conservative to be sure that the temperature would not cause trouble with flanged joints and in the steam-cylinders of the auxiliaries. The attached type were selected because they took no additional room and are self-regulating. Use of superheaters at the direct-current station shows a gain of about 9 per cent per 100° Fahrenheit of superheating in the engine economy, and while with the attached type it is impossible to make comparative tests with and without superheaters upon the same apparatus, the station economy indicates a substantial net gain by moderate superheating.

Stokers were selected that seemed to give the best results with the high-grade fuel used in New England, and with a minimum amount of repairs; the labor required to operate them is small, and very little combustible fuel is wasted in the ash pits.

Beneath the coal-bunkers small non-automatic weighing hoppers are installed. Direct-reading beam-scales are used because they are reasonably accurate, cheap in first cost, and are easily tested.

No economizers have been installed because of their doubtful value under the operating conditions of this station and of their effect on the chimney draft, which is liable to cause a reduction in the capacity of the boiler plant at the time when the maximum is needed, or else make it necessary to cut the economizers out of commission at a time when they would be most useful.

The storage of coal is a very essential feature of a large central station, and is seldom adequately taken care of. Alongside of this station and adjacent to the water front an open-air storage of from 60,000 to 70,000 tons of coal is provided where the coal is stored without any shelter and immediately on the ground. The winter's supply of coal can therefore be purchased while the freight rates are low during the summer time, which, notwithstanding the loss from weathering coal, reduces the cost of fuel delivered in the fire room.

The coal-wharf is equipped with an electric tower, operating a one-ton clam-shell bucket and one electro-hydraulic tower operating a similar bucket of 1.5 tons capacity . The electro-hydraulic tower is a new design in which hydraulic-elevator cylinders furnish the power for operating the bucket. The water pressure is obtained by a three-stage centrifugal pump driven by an induction motor. This pump is automatic in its action, and when the water pressure reaches the maximum point the pump continues running and maintains that pressure without delivering any water, until the pressure drops. The tower is operated by one man with a minimum amount of physical exertion.

The coal is conveyed from the wharf to the storage-yard by a system of conveying belts, the conveyors from the wharf to the yard having a maximum capacity of 700 tons of coal per hour. This conveying system was adopted because it was possible to obtain a very large capacity when desired, with a minimum amount of attendance and repairs.

The storage-yard is equipped with an electric reclaiming-bridge which operates a clam-shell bucket of the usual type and of two tons capacity. This bridge is so installed that it will cover the entire storage-yard, and besides taking coal from the field and putting it on to the conveyor running into the station, it is very useful to turn over the coal quickly should it show signs of heating.

The distinctive feature of this reclaiming-bridge is the fact that all the machinery for operating the bucket is installed on a trolley car running on the deck of the bridge. The operator riding on this trolley is always immediately over his work, and can control the motions of the bridge at the same time he is operating the bucket.

The water-supply for the boilers is of equal importance to that of the fuel. Water-service pipes of ample capacity for the total station are brought into it from large mains in the two adjacent streets. These will shortly be fed from separate trunk mains. For a further safeguard to the water-supply, a system of storage-tanks, with a combined capacity of 50,000 cubic feet of water or sufficient to run one turbine on the condenser for about ten days, is installed on the ground alongside the station building and at an elevation considerably above that of the feed-pumps.

As to the general arrangement of the switching, there are of necessity three bus-bar pressures, the excitation, and the possibility of a fourth pressure being required later. The engine-driven alternators generate at 2,300 volts, and the turbine-driven alternators at 6,900 volts. This latter was fixed upon after careful consideration of the location of the present business with reference to the station and of its probable growth. There is also a certain amount of 4,600-volt business which crept into the system some time previous because a considerable amount of business developed at a distance too far away for the economical use of 2,300 volts, and the standard cables on the system would safely carry only 5,000 volts. Therefore, the simplest expedient at that time was to install two-to-one transformers and supply them from the old station bus-bar. This business which started in a small way long before a turbine station was considered, had grown to a considerable size at the time the turbine was installed, and the loss in the underground cables and other apparatus—which would have no commercial value in case this pressure was changed—prohibits making any change at the present time. The turbine pressure of 6,900 volts promises to be ample for the present needs of the company, but it can be easily foreseen should the lines be extended beyond their present limits or should the business at the end of some of the transmission lines materially increase, that this pressure might be too low. If this happens, it is planned to double the pressure on the transmission lines in question and transmit in these instances at 13,800 volts. All transformers installed on these lines are built with 13,800-volt taps.

The bus-bars in each system are installed in duplicate, and so arranged that they can be cut into short sections of no more than 10,000 K.W. each by tie-switches, and any transmission line or generator can be isolated if it is desired to do so. Transmission lines are grouped with the generators on a section of bus-bar so that this bus-bar does not have to carry much current any distance lengthwise. The generator is connected to the bus-bars through one main-switch and two selector-switches. These switches are designed to open under the full station capacity, should emergency ever demand it. The transmission lines have selector-switches but no main-switches at present, space being reserved for the installation of selector-switches should they prove desirable later.

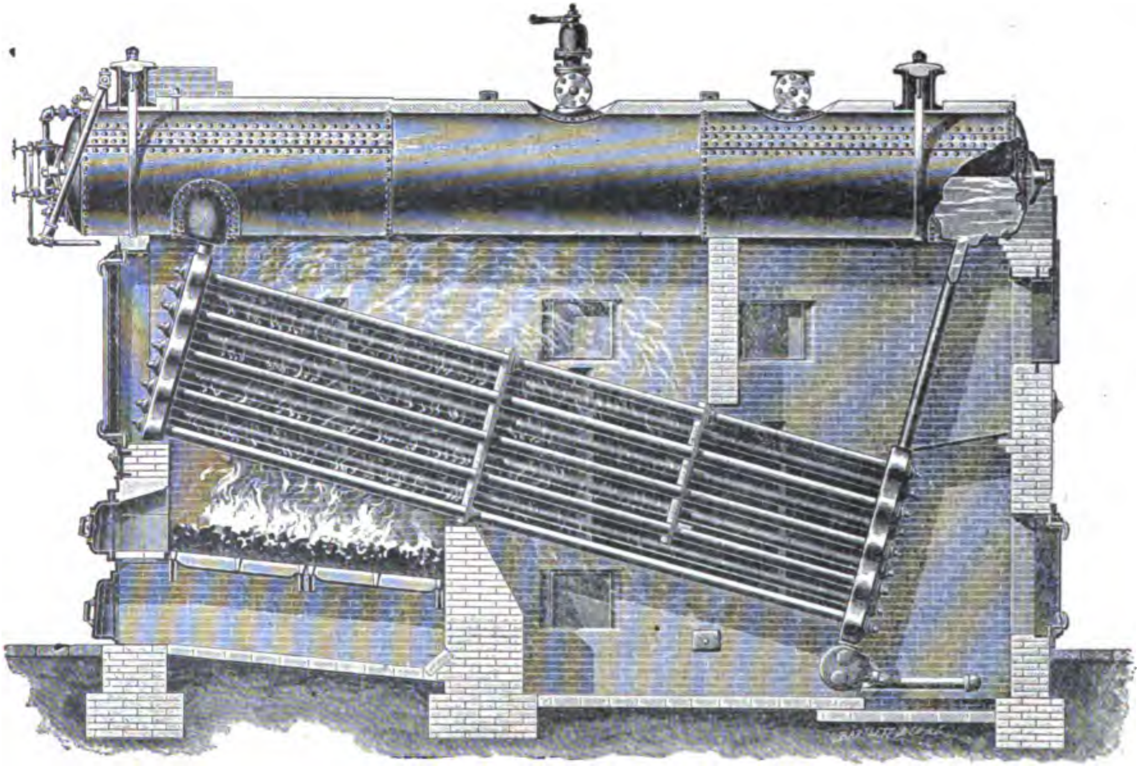
The switches are all installed on the third floor of the switch-house. The selector-switches are in two rows. Each row consists of two switches (placed back to back) running through the center of the building and immediately over the bus-bars they connect to. The main-switches are installed in two single rows, one on each side of the switch-house and against the side walls. On the floor below, the bus-bar compartments are arranged similarly to the selector-switches, two rows of two through the center of the room. In two single rows on each side wall immediately under the main-switches are grouped the instrument transformers in special compartments.

The oil-switch cells, the bus-bar chambers, and the instrument transformer chambers are all built of a light-yellow brick with a fine cement joint, the brick being selected for its low absorption properties. The barriers in the bus-bar compartments and also in the instrument compartments are of reinforced concrete with a fine, close-grained finish. These are all made in moulds and set in place similarly to slabs of alberene; they have as good insulating qualities as alberene with less absorption, are much cheaper; and furthermore are less liable to break. The bus-bar chambers are fully enclosed, small doors being left in the wall for access to the connections only. The instrument transformer cells are left open. The front of each switch-cell is enclosed with a wooden frame filled with a pane of glass which permits an inspection of the pot, while at the upper part of the frame there are a few slats for ventilation, and for vents in case of an explosion.

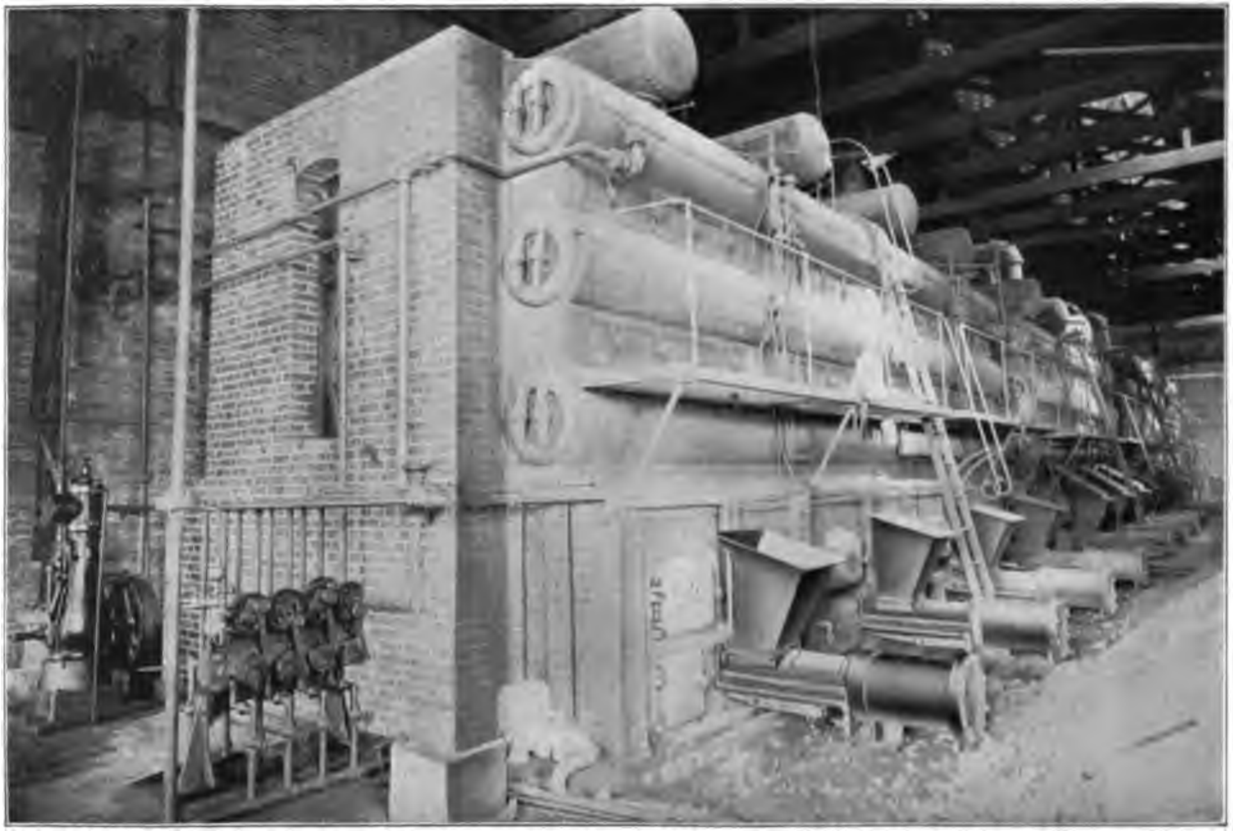
The transmission lines and also the turbine-leads and transformer-leads enter the basement of the switch-house in duct-lines which terminate in this room and at a point nearly underneath the selector-switches they connect with the upper floor. The lead-sheathed cables terminate in end-bells as close to the end of the ducts as possible, from which points cable with flame-proof braiding is carried on glass insulators and through porcelain tubes to the switches overhead. From the end of the ducts, the cables are taken in air-runs and they are so grouped throughout the basement that there is ample air-space between all cables. Provision has been made for the installation of static-discharge apparatus in this basement, but at present none has been installed.

The electrical operating-room is on the top floor of the switch-house about in the center of the building and contains nothing but the operating apparatus. Convenient stairways leading down from this room through the switch-house bring the operator in close touch with all the switching apparatus. A signal system similar to that used on board ship enables him quickly to communicate his orders to any of the generating rooms, doing this with a certainty that the order will not be misunderstood. This system also provides for an acknowledgment indicating when the order has been carried out.

All the switching apparatus with the exception of the excitation system is remote-controlled. The controller panels with all the necessary instruments are grouped in the operating-room in the form of a rectangle, facing inward so that the operator can see at a glance any panel in the room. The excitation switching is hand-controlled. The bus-bar for this is brought into the operating-room and placed between the two groups of switches controlling the engine-driven alternators and the turbine-driven alternators. The panels for the ground-detectors are installed alongside the excitation, but so that the operator has grouped at one end of the room all the apparatus which requires constant attention. The transmission-line panels, transformer panels, and others are scattered along down the room in the order that is most convenient for their installation, without reference to the sequence of the switches themselves down stairs. The excitation is furnished by one small steam-driven set of sufficient capacity to start up an engine-driven alternator in case the entire station should be shut down, three small motor-driven alternators located in the old engine-room having a capacity sufficient for all the engine-driven alternators, and three large motor-driven exciter sets, one in each of the individual turbine-rooms with sufficient capacity to supply the turbines. In addition to the motor-generator sets there is a storage-battery with a capacity of 1,000 amperes for an hour, floating on the excitation bus-bar. Besides the generator fields, there are fed from the excitation bus-bar a few other pieces of apparatus which are particularly necessary to the operating of the station, such as the motors operating the oil-switches, the relay-pumps or the step-bearings, and a few lights around the station which would be essential in case the general lighting system should give out.



BABCOCK AND WILCOX WATER-TUBE BOILER.



JONES UNDERFEED STOKERS IN STATION OF THE TOKYO ELECTRIC CO.,
TOKYO, JAPAN.

A GRAPHICAL METHOD OF RECORDING DATA OF BOILER TRIALS.

The usual method of keeping the data of a boiler or engine trial is to tabulate the readings. From these readings the results —which are also tabulated—are calculated. To the engineer in charge of the test, these figures are partially satisfactory, but for anyone else to get a good idea of their meaning, careful study is necessary. The tabulated figures give little information regarding the uniformity of conditions during the trial.

To represent the readings and conditions so that anyone interested in the subject can know them at a glance, a graphical record may be made on co-ordinate paper. This chart has so many advantages that it is well worth the little trouble. For the benefit of those not familiar with graphical representations on co-ordinate paper, a brief description is here given.

LAYING OUT THE CURVES.

The first thing to do is to find out the limits between which the readings are likely to vary. For instance, the steam pressure under working conditions will probably vary not more than ten or fifteen pounds. The engineer in charge of the plant usually knows the limits of feed-water temperature. After noting the variations of all the items, the limits may be laid off on the edge of the ruled paper.

The scale to which the readings are plotted depends upon the item. It is quite evident that the feed-water temperature curve should be plotted to a *larger* scale than the curve of flue temperatures. A little thought and calculation will easily settle these points.

As an example, let us consider the accompanying table and Fig. 1. The table shows the readings taken during a certain boiler test recently, and the curves of Fig. 1 form the graphical record of the readings. The readings are given up to 3 o'clock only, as these are sufficient to show the method.

Of course, the layout varies with each test and the scales may be chosen to suit conditions. In Fig. 1, each small division (vertical) represents the following increments:

Temperature of flue gas	20°	
Temperature of feed water	5°	
Steam pressure	2	pounds
Draft (inches of water)	.05	inch
Calorimeter (quality of steam)	.01	
Water	20	cub. ft.
Coal	200	pounds

Time is plotted along the horizontal as shown. It will be noted that all the readings except those of the amounts of coal were taken at half-hour intervals.

LOG OF TEST.

TIME	COAL		WATER METER	TEMPERATURES		STEAM PRESSURE	DRAFT	QUALITY OF STEAM
				FEED	FLUE			
7.00			226	136	460	86	.47	.97
7.30	7.30	400	267	139	496	91	.49	.98
8.00	8.05	400	304	144	500	91	.50	.97
8.30	8.55	400	337	141	514	92	.52	.965
9.00			379	140	520	93	.52	.97
9.30	9.40	600	422	134	522	91	.51	.99
10.00	10.15	400	491	130	520	91	.52	.98
10.30			534	130	510	90	.53	.97
11.00	10.50	400	564	133	518	91	.52	.98
11.30	11.25	200	610	140	520	92	.54	.98
12.00	12.00	400	640	142	480	91	.53	.98
12.30			650	140	470	90	.48	.98
1.00	1.05	600	672	142	496	86	.50	.99
1.30	1.30	400	723	136	510	90	.53	.99
2.00	2.15	400	763	150	520	91	.54	.98
2.30	2.35	400	810	152	536	93	.53	.98
3.00			850	150	536	91	.52	.98

After determining the starting-points, it is an easy matter to plot the curves. Let us take the flue temperature as an illustration. From 7 o'clock to 8 o'clock, the temperature rises 40 degrees (500 – 460 = 40), and as one division equals 20 degrees (see table above), the curve rises two divisions as shown. At 9 o'clock the reading is 520 degrees, hence the curve rises one division. By remembering the scales, each reading may be plotted as soon as taken. It is usually easier to plot the increase or decrease from the last reading; but if this is done, the plotted points should be verified occasionally by referring to the base-line of the curve in question.

PLOTTING THE CURVES.

For plotting the curves, the co-ordinate paper may be tacked on a board and kept in some convenient place so that each observer may plot his readings immediately after taking them. This is advantageous in that each observer need remember only his own scale and plot his own curve; but it may cause confusion, especially if there are many observers. If there is a sufficient number of observers, one may have charge of the plotting and either go around and get the observations, or the readings may be brought to him to plot and record as a duplicate table.

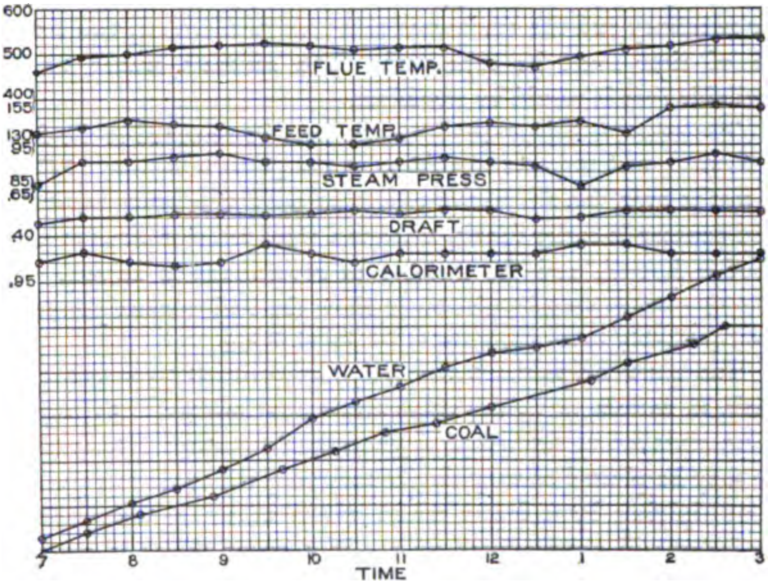


Fig. 1.

The reading and plotting of pressures and temperatures will present no difficulty, because they can be taken at stated intervals and the variation is slight. The coal and water, however, are not so easily taken care of. In the case of hand-firing, the coal may be weighed and supplied to the floor in front of the boiler in 200-pound lots. Or, all the coal for the test (as nearly as it is possible to estimate it) may be weighed at the start. If the readings are to be plotted, it is well to supply the coal in 200-pound lots as needed. If the amount of coal kept in front of the furnaces is very slight, that is, if the 200-pound lots are recorded only at the time of firing, the curve showing the amount of coal used will be quite satisfactory.

As before stated, the item of coal consumed cannot be recorded at regular intervals. As the squared paper (see Fig. 1) allows ten spaces per hour, each space is the equivalent of six minutes; and by remembering this scale, the time can be plotted very quickly. Thus, in Fig. 1, the first lot of coal was fired at 7.30, the second at 8.05, the third at 8.55, the fourth at 9.40, and so on.

With mechanical stoking, the curve of coal consumption cannot be plotted in this way, because the hoppers are filled whenever necessary and the amount of coal used between any two intervals of time must be estimated. This estimate would be so unreliable that it would be worthless.

To overcome this a speed counter may be attached to the feed mechanism, and the readings taken at the given intervals. When the test is over, the amount of coal used per 100 revolutions of the speed counter is easily found, since the total amount of coal consumed is known, and the number of revolutions is known. In this way a curve may be plotted to show the coal consumption; it would probably be as accurate as for hand-firing.

The water fed to the boiler may be measured by a meter, in a tank, in barrels, or by any other convenient method. In Fig. 1, the amounts are in cubic feet as given by the meter. These readings may be plotted as they are, or they may be reduced to pounds by multiplying by a factor which varies with the temperature. This factor will approximate 62.4. If a water meter is used, it should be carefully calibrated so that the error in this item may be reduced to a minimum.

In plotting the coal and water, it would be well to reduce the meter readings to pounds, and then plot both coal and water to the same scale. This, however, is not at all necessary.

It is a well-known fact that many short boiler tests show remarkable results as to evaporative efficiency. The excellence of these results is due largely to an incorrect estimation of the amount of fuel on the gates when starting and stopping. In making a test from a flying start, the conditions of the fires is carefully noted at the time the first readings are recorded. This usually occurs just after cleaning or a few minutes after cleaning.

To eliminate these starting and stopping errors, the graphical method will be found of great assistance. To do this, the curves should be plotted carefully and then the two ends cut out. As the water level is usually marked at the beginning of the test, careful note should be made at each reading, so that, if the water is above or below normal, the amount be allowed for.

The curves shown in Fig. 1, are constructed by connecting the points by straight lines. Some prefer to draw a smooth curve through these points.

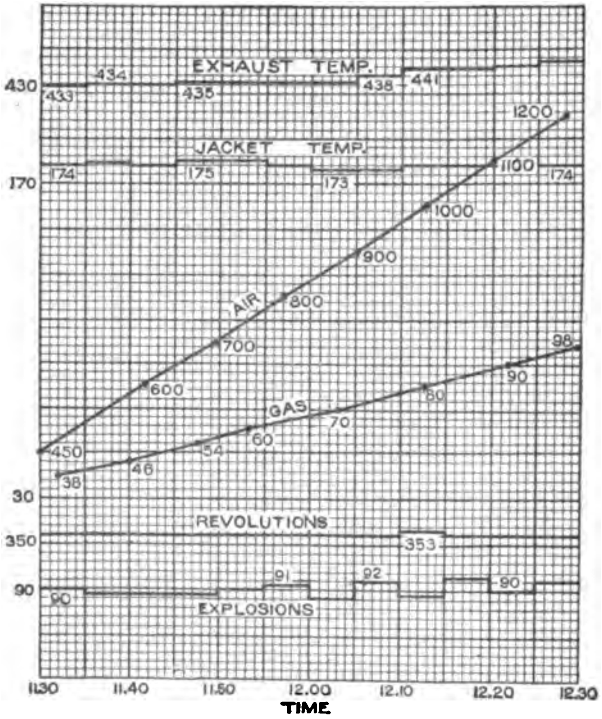
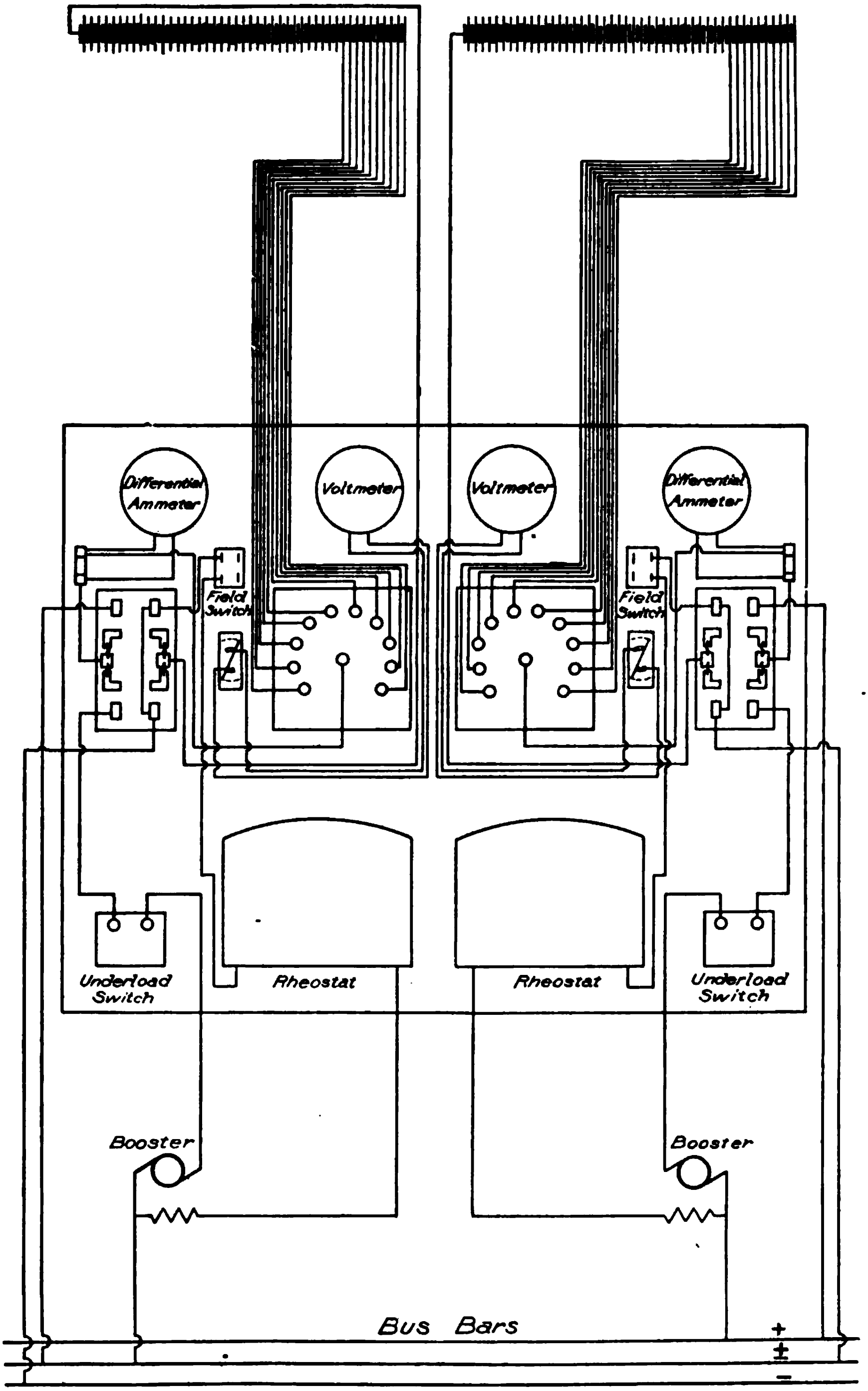


Fig. 2.

The graphical method shows inaccuracies in readings, such as counting a lot of coal twice or reading the meter incorrectly. While this is especially true of a test made while running under a steady load, the graphical log is valuable also if the load fluctuates, for the curves for coal and water should show the same relative positions to each other.

Fig. 2 is the graphical log from a test of a small gas engine. It serves to show the application of the same principle to a different test. In addition to the curves shown, the curves for gas used per indicated horse-power per hour may be plotted if there are sufficient observers to measure the cards.

The graphical method is equally valuable in tests of engines and other machinery. With necessary modifications it may be used when testing electrical machinery.



Switchboard Connections for Storage Battery Auxiliary

STORAGE BATTERIES

Storage or secondary batteries, also called *accumulators*, consist of cells in which a chemical change is brought about by passing an electric current through them, thereby rendering them capable of giving back electrical energy, or *discharging*, until they return to their original chemical condition.

Ordinarily a storage battery consists essentially of two sets of plates suspended in a chemical solution. The plates are of metal or metallic oxide, and the solution is incapable of acting upon them until an electric current is passed from one set of plates to the other. This current decomposes the electrolyte, one of its ions or constituents going to one set of plates and the remaining ion or constituent to the other. Thus two chemical elements or compounds are formed, having a tendency to combine or react; and when combination or reaction occurs on closing the circuit, the energy evolved appears as an electric current, which flows in a direction opposite to that of the charging current. This flow of current continues until the cell is restored to its original condition; when this occurs, the cell is said to be *discharged*.

A *Primary Cell* is one in which electrical energy is produced by the chemical action of one or two solutions on the plates of the cell. When the solutions or plates are exhausted, they are not restored to their original condition by the passage of an electric current in the same cell; but it is possible to regenerate or recover the solutions and metal by treating them electrolytically or chemically in other vessels.

An *Electrolyte* is a chemical compound capable of acting as an electrical conductor, and while so acting, undergoes chemical decomposition. This phenomenon is called *electrolysis*.

For example, when hydrochloric acid is decomposed by electrical energy, it is decomposed into the elementary gases hydrogen (H) and chlorine (Cl). The chemical formula for this action is,

$$2H\,Cl + \text{Electrical energy} = Cl_2 + H_2.$$

When sulphuric acid is electrolyzed, it is at first split up into hydrogen (H_2) and the radical sulphion (SO_4); the latter combines with the water of solution present and reforms sulphuric acid (H_2SO_4), oxygen being liberated. The chemical equations for the above primary and secondary reactions are:

$$2H_2O + 2H_2SO_4 + \text{Electrical energy} = 2H_2 + 2SO_4 + 2H_2O$$

$$2H_2 + 2SO_4 + 2H_2O = 2H_2 + 2H_2SO_4 + O_2$$

The modern theory of electrolysis is based upon the existence of free ions in every electrolyte. For example, a metallic salt dissolved in water is partially ionized; that is, a certain percentage is dissociated into the metal constituent and the other component part of the salt. These carry respectively positive and negative electrical charges, which are neutralized when the ions reach the negative and the positive plates of the battery. The various ions have definite velocities at which they travel or migrate through the electrolyte. The conductivity of electrolytes is entirely due to the presence of these ions, as the non-ionized portion does not conduct.

In 1802, soon after the invention of the primary cell by Volta, Gautherot demonstrated the fact that platinum wires, after being used to electrolyze saline solutions, were able to produce secondary currents. Volta, Ritter, Davy, and others noted similar effects, the phenomenon being what is commonly called *polarization.* In 1859, Planté undertook a series of experiments with the object of studying and magnifying this effect, and finally developed the Planté type of storage battery. Many of the most successful types of storage batteries of the present day are based upon Planté's invention.

Types of Storage Batteries:

Planté;
Faure;
Combination of Planté and Faure;
Non-lead.

PLANTÉ TYPES OF BATTERY

The Planté cell was originally made by placing two plates of metallic lead in a vessel containing dilute sulphuric acid. These plates were connected to an electric generator, and a current sent through the cell, which decomposed the electrolyte and oxidized the positive plate. The cell was then discharged; but the energy obtained was very small, since the action was confined to the immediate surface of the plates. By repeated charging and discharging, first in one direction and then in the other, the oxidation penetrated deeper and deeper into both plates, thus increasing the storage capacity of the cell.

The chief difficulty with the original Planté battery was the great length of time and consumption of energy required for *forming* the plates, which process, as just explained, consists in converting the surface of the plates into active materials, by repeated charging and discharging. Planté found that he could hasten this forming process by pickling the plates in dilute nitric acid, then washing them in a 10 per cent sulphuric acid solution, after which they were electrically formed. Other methods of facilitating the forming process, or increasing the active surface, are given later.

In 1881, Faure devised the method of *pasting* the lead oxide or active material directly upon the plates. This largely avoids the tedious forming process; but the plates thus produced are not so durable as the Planté elements, being more likely to disintegrate, because the paste is not an integral part of the plate.

General Principles of the Storage Battery. Any primary battery will act as a storage battery provided its chemical action is reversible. The ordinary gravity cell, for example, may be regenerated by sending a current through it in the direction opposite to that produced by it. The zinc sulphate and the metallic copper are thus reconverted into metallic zinc and sulphate of copper respectively, the chemical action being

$$ZnSO_4 + Cu + \text{Electricity} = Zn + CuSO_4,$$

which is exactly the reverse of the action in the primary cell. There are, however, practical difficulties in the continued recharging of a spent gravity cell, due to the ultimate mixture of the sulphate solutions so that the copper salt will reach the negative electrode, where it is deposited and sets up destructive local action. In some forms of primary cells, the chemical action liberates a gas that escapes, so that the action in these cases is obviously irreversible.

Chemical Action in Lead Storage Batteries. The exact nature of the chemical changes which occur in lead batteries, is not yet fully established. Planté believed the charging action to consist in the formation of peroxide of lead (PbO_2) on the positive plate, and metallic lead on the negative, which were converted into lead oxide (PbO) on both plates by the discharge. It was shown later by Gladstone and Tribe, and corroborated by subsequent investigations, that the formation of lead sulphate plays an important part.

This reaction may be represented as follows:

	Positive Plate		Electrolyte		Negative Plate
Charged Condition	PbO_2	+	$2H_2SO_4$	+	Pb
Discharged "	$PbSO_4$	+	$2H_2O$	+	$PbSO_4$
Charging Current			⋙——→		
Discharging Current			←——⋘		

According to the above equations, the active material on both plates is converted into lead sulphate when the battery is discharged. The reasons for believing this to occur are: *first,* chemical analysis shows that lead sulphate exists in the discharged plate; *second,* the density of the electrolyte decreases during the discharge of the cell, corresponding to the consumption of sulphuric acid and the formation of water, as shown in the above reactions; *third,* on thermochemical grounds, the combination of lead and oxygen as lead oxide (PbO) does not evolve sufficient energy to account for the E. M. F. produced.

Storage Batteries of the Planté Type. It was noted that the first difficulty met with in the making of Planté plates was the inordinate length of time and cost of current necessary to form them; and it was also shown how Planté treated them with nitric acid to hasten this action. Other methods are used to facilitate the formation; these are tabulated as follows:

1. *Mechanical Action:* Laminated plates, made up of lead ribbons. The surface of the plate is grooved with some forming tool. Built up of lead wires, etc.
2. *Chemical:* Treating the plates in some pickling bath, to produce initial oxidation.
3. *Electrolytic:* Forming a plate of some compound of lead or an alloy, and either reducing the compound or eating the foreign matter away, leaving a porous lead plate.

Gould Storage Battery. This battery is made by the Gould Storage Battery Company, of New York, and the plates are produced by a combination of the first and third methods. The plates or blanks are placed in steel frames and given a reciprocating motion between two revolving shafts which carry grooving discs, giving the plates a surface as shown in Fig. 1. No lead is removed by this process; but the surface is ploughed up. It is then subjected to electro-chemical treatment to form the active material. The types manufactured range in size from a cell of three plates 3 inches by 3 inches, to one of 105 plates, each 15.5 inches by 31 inches; and in capacity from 5 ampere-hours in the smallest size to 17,000 ampere-hours in the largest.

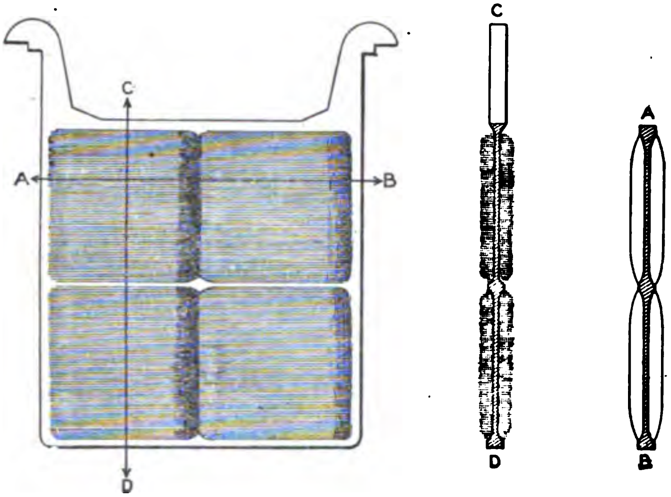


Fig. 1. Gould Storage-Battery Plate.

Bijur "High-Duty" Battery. Batteries of this type are manufactured by the General Storage Battery Company, of New York. They are made in standard sizes ranging from 6 ampere-hours to 12,688 ampere-hours, the smallest cell being made up of two plates, one positive and one negative, each 3 inches by 3 inches, suspended in a small glass jar. The largest type comprises 67 plates, each 15¾ inches by 31¾ inches, suspended in a lead-lined tank. Some of the standard sizes manufactured are shown in Table I.

Both positive and negative plates are of the Planté type, and are of the same general design, Fig. 2. Each plate consists of the grid or supporting frame, made up of pure lead containing a small percentage of refined antimony, producing a rigid inoxidizable supporting and conducting member for the active lead. In the openings of this rigid framework are welded gratings or *grills* of pure lead. Each grill consists of vertical strips supported by heavier horizontal

TABLE I

Data, Bijur High-Duty Battery

Type	BB	DDS	C	D		E		F		G		K		L	
Size of Plate (inches)	3x3	4⅛x8¼	3x3½	5½x5⅝		8⅛x8		10⅝x11		15¼x16		18¼x18⅝		15¾x31¼	
No. of Plates	2	2	7	5	11	5	15	7	19	11	57	21	71	19	67
Discharge Rate (in Amperes) 8 hrs.	¾	3	4.5	6	15	12	42	36	108	120	672	360	1,260	432	1,584
5 "	1	4.2	6.5	8	21	17	59	50	151	168	942	504	1,760	605	2,218
3 "	1½	6	9	12	30	24	84	72	216	240	1,344	720	2,520	864	3,168
1 "	3	12	18	24	60	48	168	144	432	480	2,688	1,440	5,040	1,728	6,336
Normal Charge Rate	¾	3	4.5	6	15	12	42	36	108	120	672	360	1,260	432	1,584
Outside Dimensions of Glass Jar: Width	2⅜	3⅛	6¼	4¾	9⅛	5¼	13½	7⅜	....	....	....	....	....	....	....
Length	3⅞	6⅛	6¼	7⅞	8⅛	9	9½	12¾	....	....	....	...	....	....	....
Height	5⅜	12	10	10	10	12	12	16	....	....	....	....	....	....	....
Outside Dimensions of Lead-Lined Tank: Width	....	....	....	....	....	....	....	....	21¾	15⅛	54⅞	25	66½	23½	63¼
Length	....	....	....	....	....	....	....	....	15	19¾	21½	24½	24½	22	22
Height	....	....	....	....	....	....	....	....	17⅝	26	27½	31½	31½	48⅞	49⅞
Outside Dimensions of Glass Tanks: Width	....	....	....	....	....	....	....	....	20¼	....	....	....	....	....	....
Length	....	....	....	....	....	....	....	...	13	....	....	....	....	....	....
Height	....	....	....	....	....	....	...	....	18¼	....	....	....	....	....	....
Weight of Complete Cell, Incl. Acid and Containing Vessel (Pounds)	5⅝	19	25½	36	75	61	161	152	516 466	603	2,670	1,486	4,706	1,947	6,070

members which act as I-beams to stiffen it laterally, and which, with the vertical ribs, form the oxide cells. The active material is formed from the grill expanding as it grows in each of the minute oxide cells, thus locking itself in place.

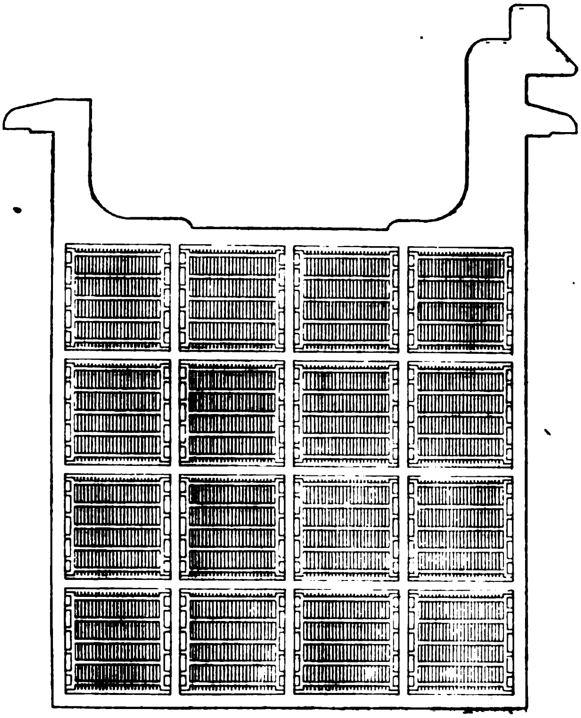


Fig. 8. Bijur High-Duty Battery Plate.

The grills have no central web; and, being open structures, a through - and - through circulation of electrolyte is obtained. The grills are held on both sides by the alloy frame to which they are welded. A suitable space is provided between each end of the grill and grid to allow for vertical elongation, while the spacing of the strips accommodates the lateral expansion. The grills are therefore free to expand in every direction, thus avoiding the tendency to set up strains in the plates, which might cause them to buckle.

In welding the grills to the grid or frame, a heat process only is employed; no solder, flux, or foreign substance of any kind is used. Since the grill is an open structure, grown from which is a very thin layer of active material, and as this active material does not entirely close the small oxide cell, the gases evolved at high rates of charge have ready means of escape. This results in lower E. M. F.'s required for charging, and the acid diffusion thus obtained also maintains the E. M. F. when discharging at excessive rates.

With the closely adherent layers of active material in intimate contact with the metallic lead, and the absence of concentration of the electrolyte in the pores of the active mass, due to the diffusion, excessive sulphating does not occur.

The loss of negative capacity, due to shrinkage of the active material into a metallic mass, is avoided in this particular plate, by a special treatment which the plates undergo.

FAURE TYPES OF BATTERY

The difficulty with this type is the tendency to disintegrate or buckle. Various means intended to increase the permanency of adhesion of the active material have been suggested, of which the most important are as follows:

1. Plates are grooved, roughened, or *pocketed*.
2. Plates are entirely perforated, the holes being circular, or rectangular, and varying in cross-section; some have a uniform section through the grid

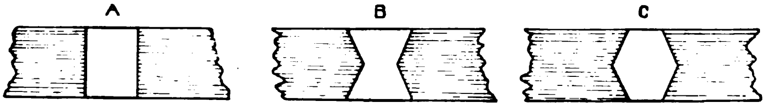


Fig. 3. Different Cross-Sections of Faure Plate Perforations.

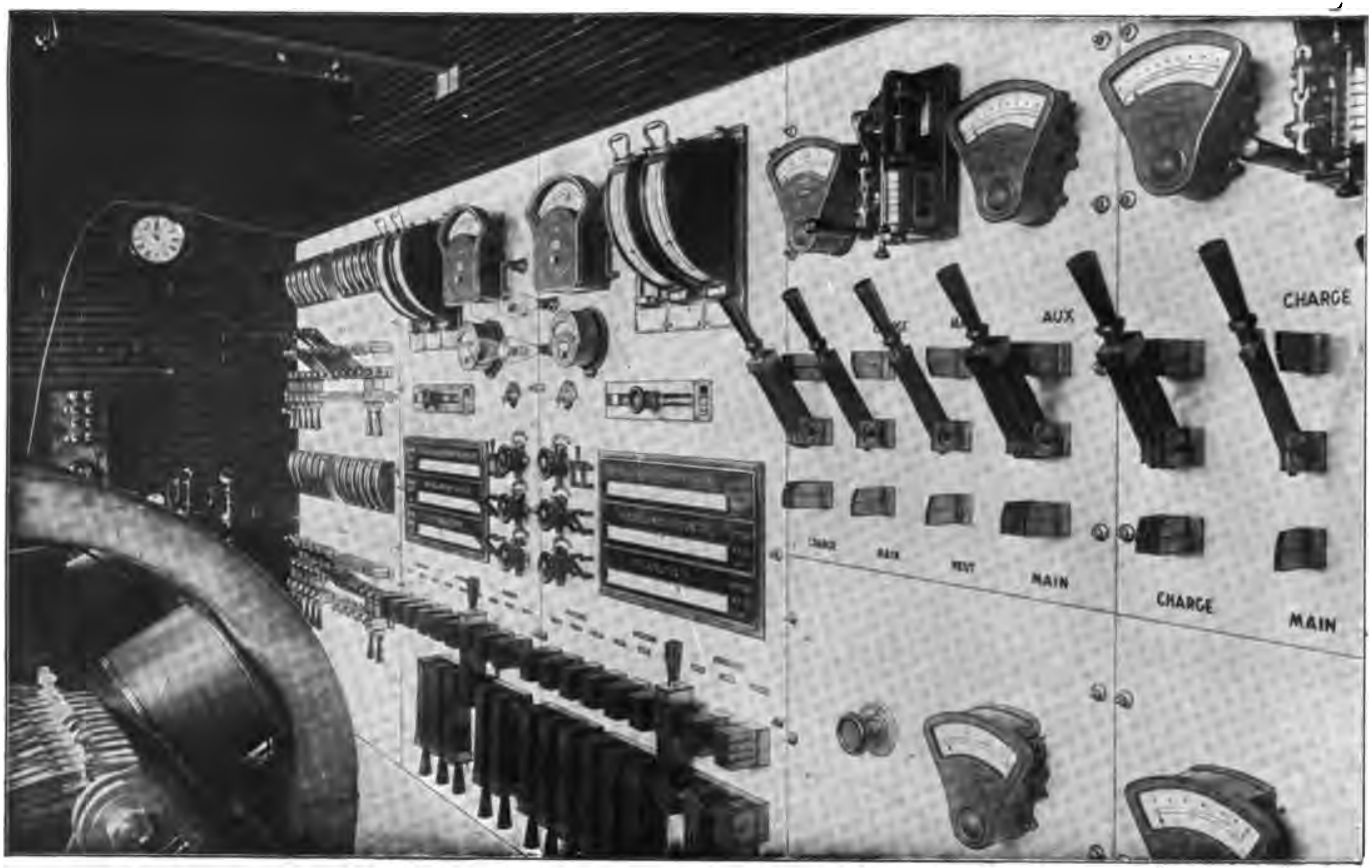
(*A*, Fig. 3); others are contracted at the center (*B*); and again they have been expanded at the center of the grid (*C*).

3. The active materials may be enclosed in either a conducting or a non-conducting cage.
4. The plates may be made up entirely of active material.

Faure cells usually have a greater weight efficiency than those of the Planté type, because the proportion of active material may be made greater.

E. P. S. Battery. This is one of the most important of the Faure type, its name being the initials of the Electric Power Storage Company by which it is manufactured in England. It is sometimes called the "Faure-Sellon-Volckmar" cell, being based upon the work of these and several other inventors.

The plates consist of lead grids cast in an iron mould, and have the cross-section shown in Fig. 4. The later types have a thin perforated strip of lead running across each opening midway between the edges. The holes *A* in the grid are completely filled with a paste of red lead or minium (Pb_3O_4) and dilute sulphuric acid, for the positive;



Storage Battery Switchboard

Detroit Edison Company

while the paste for the negative consists of minium, or litharge (PbO), and dilute sulphuric acid, or a magnesium sulphate solution. These pastes are pressed into the grids and dried.

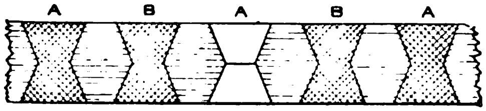


Fig. 4. Section of E. P. S. Battery Plate.

The plates are hardened in dilute sulphuric acid, after which they are ready for forming. A strong current of 48 hours' duration is required for the positive plate, and twenty-four hours is required for the formation of the negative plate. To prevent short-circuiting after the cells are set up, the plates have glass rod separators placed between them.

The E. P. S. batteries are made in many different sizes and forms, of which the L type is a good example, being used extensively in isolated plants. Data of this type are given in Table II.

TABLE II

Data, E. P. S. Accumulator, L Type

No. of Plates	Maximum Normal Charge or Discharge Rate	Capacity (Ampere-Hours)	Approximate External Dimensions			Weight Complete with Acid (Wooden Cell)
			Length	Width	Height	
7	13 amperes	130	5½ in.	13½ in. for wooden and 12 in. for glass cell	18 in. for wooden and 13½ in. for glass cell	74 lbs.
11	22 "	220	8 "			107 "
15	30 "	330	9½ "			143 "
23	46 '	500	14½ "			228 "
31	60 "	660	19 "			286 "

One of the smaller types of the E. P. S. battery is used extensively in England in electric vehicle work.

Exide Battery. This type is manufactured by the Electric Storage Battery Company, of Philadelphia, Pa., chiefly for electric vehicle duty. The plates are of the Faure type, and consist of lead-antimony grids (about 5 per cent antimony) pasted with oxides of lead.

The grid for the positive plate is of the cage type, consisting of thin vertical ribs the edges of which are flush with the faces of the plate and connected by small bars of a triangular cross-section; the bars on one face are staggered with respect to those on the other side. This finished form is then pasted up with red lead (Pb_3O_4), and formed in the usual way; the thickness of the finished plate is about $\frac{7}{32}$ inch. From this description it is evident that the plate is made up in accordance with method 3 described on page 8, the enclosing cage being of conducting material. The active material is in the form of rectangular pencils extending from the top of the plate to the bottom. The thin, flat ribs are on two sides of these pencils; and the triangular cross-pieces are imbedded in the other two sides which constitute the faces of the plates. The Exide cell is shown in Fig. 5.

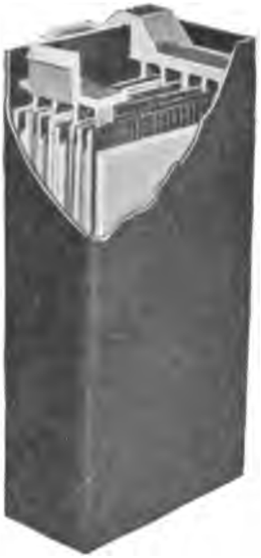


Fig. 5. Exide Battery.

The negative plate consists of a thin antimony-lead sheet, with a comparatively heavy frame of cast lead. The body of the sheet is perforated at regular points, about half an inch apart. These perforations, being made by a tool which does not remove the material, are not actual punchings; but are simply holes torn in the plate, leaving the surrounding material in ragged projections which curve back towards the sheet, forming, as it were, a series of hooks. These projections are formed on both sides of the plates.

The grid is then pasted with litharge (PbO) on both faces; it is held to the plate by the "hooks," as well as being riveted by passing through the holes which the projections surround. The thickness of this finished plate is about $\frac{3}{16}$ inch.

When assembled, the plates are placed in rubber jars of dimensions shown in Table III, and separated from one another by wooden partitions. In addition, a perforated rubber sheet is placed against the faces of the positive plates.

TABLE III

Data, Exide Cells*

Type	M. V.							P. V.			
No. of Plates	7	9	11	13	15	17	19	5	7	9	11
Discharge 4 Hours (Amperes)	21	28	35	42	49	56	63	12	18	24	30
Size of Plates—											
Length (inches)	5¾	same	same	same	same	same	same	4 13/16	same	same	same
Height (inches)	8⅝	same	same	same	same	same	same	8⅝	same	same	same
Outside Measures of Rubber Jars—											
Width (inches)	2 7/16	3¼	4¼	4 11/16	5 3/16	6¼	7 3/16	1 13/16	2 9/16	3¼	4¼
Length (inches)	6 3/16	same	same	same	same	same	same	5 3/16	same	same	same
Height (inches)	11½	same	same	same	same	same	same	11½	same	same	same
Weight (lbs.)—											
Elements	15¾	20¼	25½	30¼	35	40	44¾	9¼	13¼	17¼	21⅛
Electrolyte	2½	3½	4½	6¼	7	8	8¾	1½	2¼	3	4⅛
Complete Cell	19½	25½	31½	38½	44½	50	56	11½	17½	21½	27½

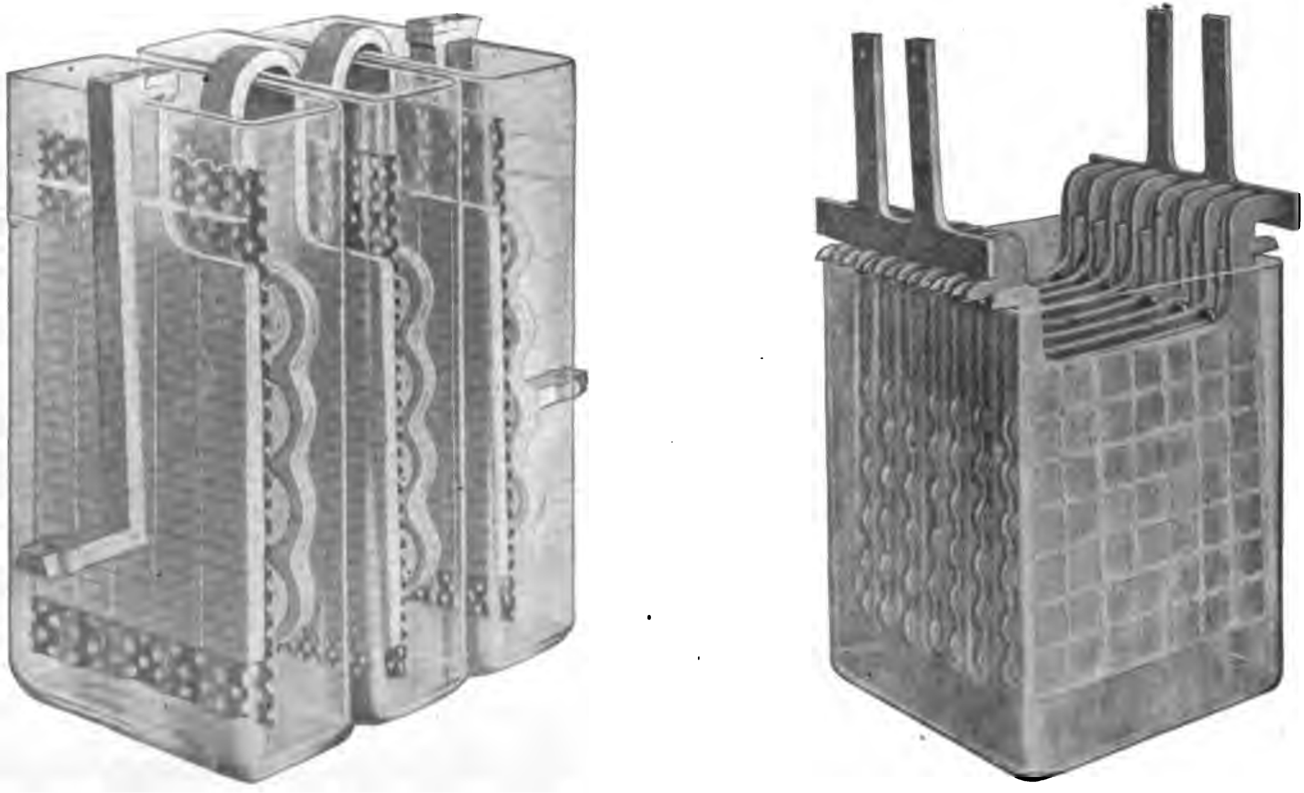
*Note.—For data on the "Express Type" of Exide cell, see literature of the Electric Storage Battery Company, Philadelphia, Pa.

The *brougham* or *hansom* battery of this type of cells consists of 44 cells of TV–9 size, having four positive and five negative plates. The weight of this outfit complete with tray is about 1,659 pounds; the capacity, 156 ampere-hours (4 hour, 39 ampere rate); the average voltage during discharge, about 1.98 volts per cell, or 87 volts for 44 in series; the total watt-hour output being therefore 13,572, or 8.18 per pound of battery complete including trays.

COMBINATIONS OF PLANTÉ AND FAURE TYPES

Chloride Battery. In the form which was manufactured until recently by the Electric Storage Battery Company and allied companies in England, France, and Germany, the Chloride Battery is a compromise between the Planté and Faure types, the positive being a Planté type and the negative of practically the Faure type.

The principal features in the manufacture of this battery are as follows: The first step is the production of finely divided lead, which is made by directing a blast of air against a stream of the molten metal, producing a spray of lead which, upon cooling, falls as a powder. This powder is dissolved in nitric acid (HNO_3) and precipitated as lead chloride ($PbCl_2$) on the addition of hydro-



B. T.—Couples in Glass Jars.

Fig. 6. The Chloride Battery.

Type F—15 Plates in Glass Jar.

chloric acid (HCl). This chloride, washed and dried, forms the basis of the material which afterwards becomes active in the negative plate. The lead chloride is mixed with zinc chloride and melted in crucibles, then cast into small pastiles or tablets about $\frac{3}{4}$ inch square and of the thickness of the negative plate, which, according to the size of the battery, varies from $\frac{1}{4}$ inch to $\frac{5}{16}$ inch. These tablets are then put in moulds and held in place by recesses, so that they clear each other by .2 inch and are at the same distance from the edges of the mould. Molten antimonious lead is then forced into the mould under about 75 pounds pressure, completely filling the space between the tablets. The result is a solid lead grid, holding small squares of active material. The lead chloride is then reduced by stacking the plates in a tank containing a dilute solution of zinc chloride, slabs of zinc being alternated with them. This assemblage of plates constitutes a short-circuited cell, the lead chloride being reduced to metallic lead. The plates are then thoroughly washed to remove all traces of zinc chloride.

In the new form of negative plate which has replaced the chloride type just discussed, the negative consists of a pocketed grid, the openings being filled with a litharge paste; it is then covered with perforated lead sheets, which are cast integral with the grid.

The positive plate is a firm grid, composed of lead, alloyed with about 5 per cent of antimony, about $\frac{7}{16}$ inch thick, with circular holes $\frac{25}{32}$ inch in diameter, staggered so that the nearest points are .2 inch apart. Corrugated lead ribbons $\frac{7}{16}$ inch wide are then rolled up into close spirals $\frac{25}{32}$ inch in diameter, which are forced into the circular holes of the plate. These spirals are electrochemically formed into active material. The process requires about thirty hours; at the same time, the spirals expand so that they tend to fit still more closely in the grids. This form of positive is that known as the *Manchester Plate.*

Recent types of "Chloride accumulator" are shown in Fig. 6. In setting up the cells, the plates are separated from one another by thin wood partitions having vertical grooves to facilitate the rising of the gases. These separators are stiffened by split wooden pins slipped over them. Sometimes glass tubes are used as separators.

Table IV gives data of the various types and sizes of cells. To save space, only the smallest and largest sizes of each type are given;

TABLE IV
Data, Chloride Battery

Types		B	C		BT	CT	PT	D		E		F		G		R*		H	
Size of Plate, inches...		3x3	4⅜x4		3x4	5x5	8¾x5	6x6		7¾x7¾		11x10½		15½x15½		18⅝x18⅝		15½x31	
No. of Plates....		3	3	7	2	2	2	3	13	5	15	9	27	11	75	25	75	21	75
Discharge in Amperes	For 8 hrs.	⅝	1¼	3¾	¾	1½	3	2½	15	10	35	40	130	100	740	360	1,110	400	1,480
	5	⅞	1¾	5¼	1	2	4¼	3½	21	14	49	56	182	140	1,036	510	1,550	560	2,072
	3	1¼	2½	7½	1½	3	6	5	30	20	70	80	260	200	1,480	720	2,220	800	2,960
	1	....	....	....	....	....	....	10	60	40	140	160	520	400	2,960	1,440	4,440	1,600	5,920
Normal Charge Rate...........		⅝	1¼	3¾	¾	1½	3	2½	15	10	35	40	130	100	740	360	1,110	400	1,480
Outside Dim. of Glass Jars (inches)	Width	2½	3½	5¼	1¾	2¼	2½	3¼	11	5½	11	9	No glass jars for these large sizes.						
	Length	4	5¼	5¼	3¾	6¼	6	7⅞	8¼	9⅛	9⅛	12⅝							
	Height	6½	7¼	7¼	6¾	8	12	9½	9½	11⅜	11⅜	17							
Outside Dim. of Lead-Lined Wooden Tanks	Width	....	....	....	....	....	....	....	....	....	....	13⅛	28⅜	15⅛	69⅞	24¾	24¾	25⅛	69⅞
	Length	....	....	....	....	....	....	....	....	....	....	15	15	19¾	21½	28⅜	69⅞	21½	21½
	Height	....	....	....	....	....	....	....	....	....	....	20¼	20¼	26	27⅞	31½	32½	48¾	49¾
Weight of Cell Complete (lbs.)		5½	10½	19	3½	7½	13½	19½	64	48¾	112	175	....	....	....	....	....	....	...
Ditto. Lead-Lined Tanks...		....	....	....	....	....	....	....	....	....	....	250	615	561	3,260	1,641	4,616	1,885	5,986

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* This size of cell is listed by its manufacturers on the 6, 3 and 1 hour rates; but for purposes of comparison it is brought to the same basis as the other sizes.

but in all cases intermediate sizes are made with every odd number of plates. The capacities, weights, etc., are of course nearly proportional to the number of plates.

The smaller sizes are provided with either rubber or glass jars, and the larger ones, from F up, with lead-lined tanks.

Tudor Cell. This type is very extensively used in Europe, and to some extent in this country, although it is no longer manufactured here. The American patent rights are controlled by the Electric Storage Battery Company.

The plates consist of rolled, grooved sheets as shown in Fig. 7, *A* being the hollows or grooves into which the paste is set, and *B* the lead frame. The thickness of the plate between opposite grooves is about .12 inch for the positive and about .06 inch for the negative. The width of grooves on the positive plate is also about .12 inch, while on the negative it is about .08 inch. The grooves are first coated with a thin layer of peroxide of lead (PbO_2) by electrolysis, and then packed with the oxides as required; the plates are then rolled to *fix* the paste. This treatment of the grid with an electrolytic bath before applying the active material, is covered by United States patent No. 413,112.

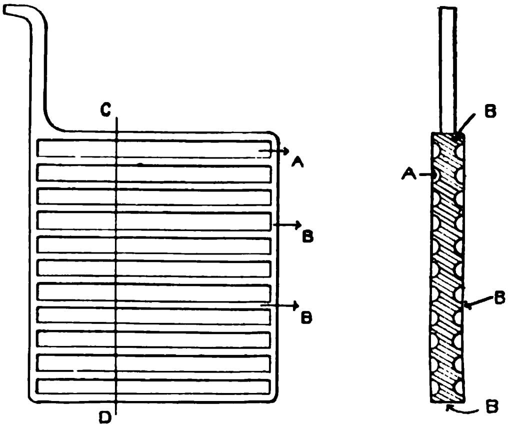


Fig. 7. The Tudor Battery Plate.

TABLE V

Tudor Cells

Type	Available Capacity	Maximum Current (in amperes)		Dimensions of Cells (in centimeters)			Total Weight
	Amp.-Hours	Charge	Discharge	Length	Width	Height	Kgms.
I	26	6	8	12	21	35	10
V	91	21	28	30	21	35	30
X	270	54	72	42	42	55	110
XIV	630	126	168	74	42	55	230

In addition to the sizes given in this table, all the intermediate sizes are made.

Lithanode. Mr. Desmond Fitzgerald has made storage batteries with a positive plate consisting entirely of active materials made up of litharge (PbO) mixed with ammonium sulphate $(NH_4)_2SO_4$ which he pressed into the required shapes. This plate is converted into peroxide by chemical treatment. The negative consists of the ordinary lead plate. While this cell has an exceedingly high weight efficiency, it is not of much commercial importance, though used considerably in laboratory work.

It is the tendency in Europe to make the positive plate of the Planté form, and the negative of the Faure or pasted type. The reason for this is that the Planté form is hard to make; and as the activity is small on the negative, the pasted plate is good enough.

The practice in lead batteries is to make the negative plate of greater capacity than the positive, as the charging and discharging of a cell in service tends to produce or form more active material on the positive plate, whereas the negative plate is made to decrease, so that allowance for this is made as above stated. A still further allowance is made to cover this action, by always having one more negative than positive plate in a cell.

Storage Batteries Containing Metals Other than Lead. It has already been stated that almost any primary cell will act more or less as a secondary cell; as, for example, the common gravity battery. A great many have been devised in which the lead in one or both of the plates has been replaced by some other metal. For example, Reynier made the negative plate of zinc instead of lead, this zinc in discharging being converted into zinc sulphate, which dissolved in the electrolyte. The substitution of zinc for lead secures an increase in initial E. M. F. from 2.2 to 2.5 volts, and also allows of a considerable reduction in weight, since for the storage of a given amount of energy the weight of the zinc required is much less than that of the equivalent lead. A difficulty with this type of cell is the formation of *trees* of zinc on the negative plate during the charging process, which are likely to fall off or extend across to the positive plate, thus short-circuiting the cell.

Another difficulty is the difference in density of the solution between the top and bottom of the plates, the tendency being to exhaust the zinc sulphate from the upper portion of the liquid during charging. In order to avoid this trouble, the plates have been arranged horizontally, so that the density would be uniform for each plate; but the difficulty then arises that the gases which form to a certain extent in almost all batteries collect between the plates and interfere with the chemical action and the passage of the current.

A similar type of cell has been manufactured by the Union Electric Company of New York, in which the negative plates consist of thin sheet copper covered with an amalgam of zinc, and the positive plates are made up of laminæ of lead held together by leaden rivets and perforated with numerous small holes, these positives being formed by the Planté process.

Waddell-Entz Accumulator. The copper alkali-zinc primary battery of Lalande, Chaperon and Edison being reversible in action, can be used as a storage battery. Waddell and Entz have constructed accumulators on this principle. When discharged, the positive plate consists of porous copper; on charging, the electrolyte is decomposed, metallic zinc being deposited on the negative plate; the porous copper of the positive plate is oxidized, and the liquid becomes converted into a solution of caustic potash (potassium hydrate).

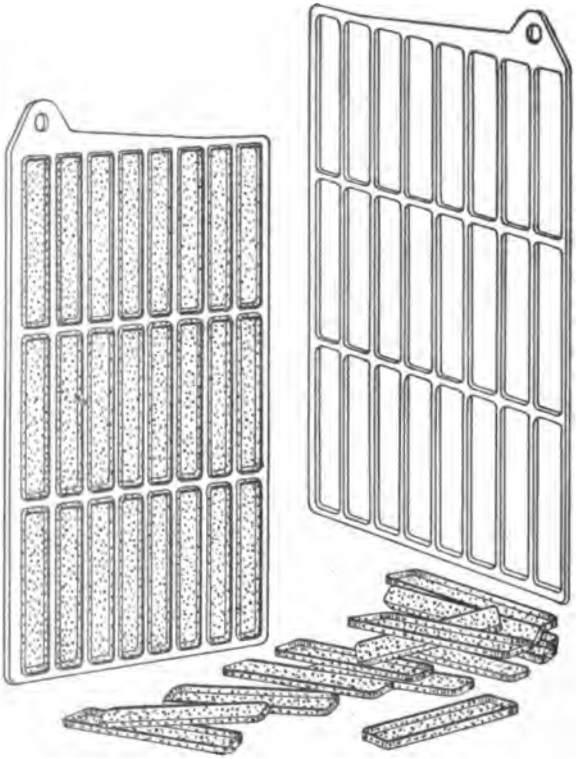


Fig. 8. Plates and Receptacles of the Edison Cell.

This storage battery was formerly used with considerable success for traction purposes; but its E. M. F. is so low, being only about .7 volt, that it would require 170–180 cells for the ordinary 110-volt electric-lighting circuit, allowing for loss of potential in the battery and conductors. This number is three times as great as is required with the lead battery. This is a serious objection to this or any other low-voltage cell.

Edison Storage Battery. The standard cells of this type are 13 inches high, 5.1 inches wide, and vary in length according to their rating, the various capacities being obtained by simply increasing the number of plates. The positive and negative plates are alike in appearance, and consist of rectangular grids, of nickel-plated iron, each about 9½ by 5 inches by .025 inch, punched with three rows of rectangular holes, eight holes to the row (Fig. 8), each hole being filled by a shallow perforated box of nickel-plated steel, the perforations being very fine, about 2,500 per square inch.

The difference between the positive and negative plates is entirely in the contents of the perforated receptacles; those for the positive plate containing a mixture of oxide of nickel and pulverized carbon, the latter being employed to increase the conductivity of the active material. The compartments of the negative plates contain a finely divided oxide of iron and pulverized carbon. When filled, these receptacles are secured to the grid by placing them in the openings of the same, and subjecting the assembled plate to a pressure of about 100 tons, which expands the pockets and fixes them firmly in the grid. A set of assembled plates as employed in a complete battery, is shown in Fig. 9.

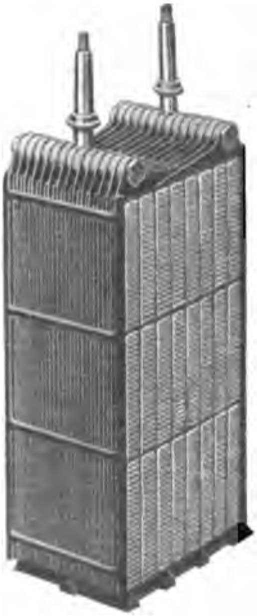


Fig. 9.
Complete Edison Cell.

The electrolyte consists of a 20 per cent solution of caustic potash, which, however, undergoes no chemical change during the process of charge or discharge, acting simply as a conveyor of oxygen between the plates. The charging current, entering at the positive plates, oxidizes the nickel compound to the peroxide state, and reduces the iron compound in the negative plates to a spongy iron mass. The containing vessel consists of nickel-plated steel; and the plates are strong individually and close together, being separated by thin strips of vulcanized rubber, thus forming a compact mass. The terminals of the plate pass through the cover of the cell, from which they are insulated by vulcanized rubber bushings.

The electrical features of the Edison cell are as follows:

Average voltage of charge at normal rate, 1.68.
Average voltage of discharge at normal rate, 1.24.

A set of charge and discharge curves of a 180-ampere-hour cell is shown in Fig. 10. This battery is rated at 30 amperes for a period of six hours. The various cells have a weight efficiency of 11.5 to 13.2 watt-hours per pound, depending upon the size. The watt efficiency under normal working conditions is about 60 per cent. The charging and discharging rates are alike, and cover wide ranges. A cell may be charged at a high rate in one hour, without apparent detriment except lowering the efficiency slightly. It is not appreciably influenced by temperature changes, and may be fully discharged to the zero-point of E. M. F., or even charged in the reverse direction, and then recharged to normal conditions, without suffering loss in storage capacity or other injury. The best results are obtained when twice as many positive as negative plates are employed; and the standard cells are made up on this basis. This type is intended especially for electric automobile service, by virtue of its high weight efficiency and its ability to endure rough mechanical as well as electrical treatment. The same qualities would also adapt it to portable electric-lighting purposes.

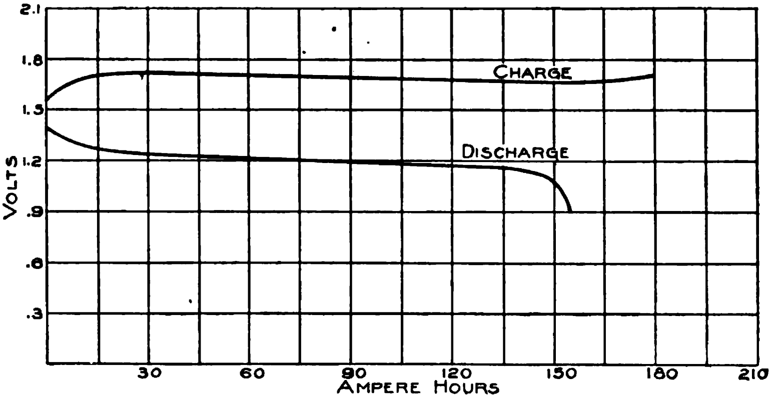


Fig. 10. Charge and Discharge Curves of Edison Cell.

MANAGEMENT OF STORAGE BATTERIES

In describing the handling of storage batteries, the various types of lead cells will be considered, as they constitute a very large majority of the cells in commercial use.

Battery Room. In the installation of a battery, the first point to be considered is its location. The room for this purpose should be dry, well ventilated, and of a moderate temperature; otherwise, not only will the evaporation of the electrolyte be excessive, but if the temperature be very high, the plates themselves will be affected and their life shortened. The floor, walls, and ceiling must be of some acid-proof material, brick or tile being preferable, and the floor so made as to drain readily, an outlet being provided to the drainage system. If the room should be an old one, and have a wooden floor, the floor should be coated with asphaltum paint, and lead trays placed below the batteries; any woodwork or ironwork in the room should be likewise treated.

The room should be sealed from the rest of the building, and located near the generating machinery and distribution switchboard, so that the copper cables may be low in cost. The windows in the battery room should be of either ground or painted glass, so that no direct rays of the sun may strike the cells, as the heat might crack the cells (glass) or increase the activity of the acid, which is not desirable.

In case the battery installation is in a cold climate, some device for keeping the electrolyte at a moderate temperature must be used.

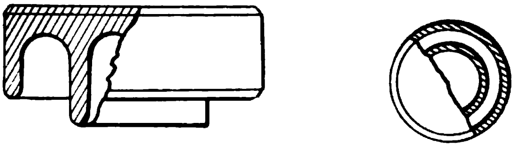


Fig. 11. Glass Insulator for Battery Support.

Setting Up the Cells. The battery is usually placed on the floor, or upon strong wooden shelves; Fig. 11 shows a form (made of glass or porcelain) adapted to cells of medium size. Iron stands are sometimes used for large and heavy cells, but they must be protected from acid fumes and drip by several coats of an acid-proof paint. Wooden stands should be varnished, painted, or soaked in paraffin for the same reason. It is important to have every cell accessible for inspection, cleaning, and removal, it being desirable to reach both sides of the cell. There should also be sufficient headroom between shelves so that the elements may be lifted out.

It is highly important that the cells be thoroughly insulated from one another, to avoid leakage of current. This is accomplished by standing each cell on four insulators of porcelain or glass of the design shown in Fig. 11. Glass is now almost universally employed because porcelain is frequently found to deteriorate gradually as a result of the action of the acid fumes.

Lead-lined tanks for 500-volt installations are usually set as follows: The floor is covered with a layer of glazed tile or brick; on this are placed two wooden stringers about 3 by 4 inches, carefully painted with asphaltum varnish or some acid-proof paint. Under each tank are set four or more insulators held in place by wooden pegs which are kept in position by pouring melted sulphur around them. Sometimes the insulators have short, threaded projections on the top, which are screwed into the bottoms of the tanks. On top of these are placed the battery tray and battery as indicated in Fig. 11.

In the case of 125-volt installations, the insulators are sometimes set directly on the tile flooring, which has been leveled by running molten sulphur under the tiling.

Oil insulators were at first used; but oil collects and holds dust, and, as dust is likely to cause leakage, they are no longer employed. For very large lead tank outfits, a double system of the supporting construction shown in Fig. 12 is used, but with individual stringers for each cell.

Glass cells are often set on wooden trays, which are filled with sand to distribute the strains and absorb the drip. Sawdust was formerly also used; but it becomes carbonized by the acid drip, and, as this is likely to cause leakage, it has been abandoned.

In connecting the cells, which are usually put in series, great care should be taken to join the positive terminal of one cell to the negative of the next, and so on. The color of the plate is the best indication of its polarity, the positive plate being a light brown when discharged and a chocolate color when charged, while the negative varies from a light to a dark slate color.

It may be noted at this point, that the nomenclature concerning storage batteries is different from that of primary cells. The positive

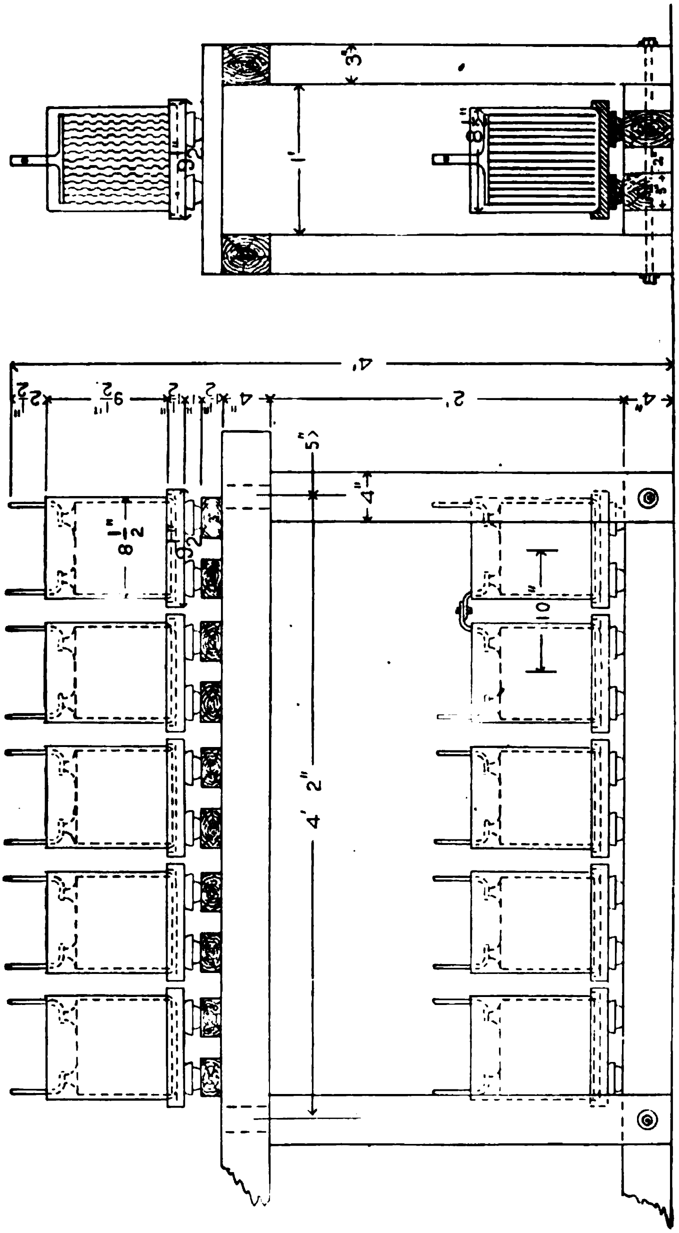


Fig. 12. Shelf Construction for Battery Support.

plate in the former is the peroxide plate (brown), and is that one from which the current flows out in discharging; whereas that would be the negative plate of a primary battery.

The positive pole or terminal in a storage battery is an extension of the positive plate, and is connected to the positive terminal of the dynamo in charging; consequently there is much less cause for confusion of terms than there is in the primary cell.

It is well to test the polarity of each cell and of the circuit, before making connections. This may be done with any form of pole-tester, or by the positive expedient of dipping the two terminals in dilute sulphuric acid, the one from which the most bubbles arise being negative. The connections should be scraped clean and screwed up very tight, then coated with acid-proof paint to avoid corrosion. The most satisfactory way to connect up a cell is to weld or *burn* the positive terminal to the negative terminal of the next cell, though soldered connections are good.

This soldering is done as follows: Two strips of lead and the terminals to be connected are very carefully cleansed; the lead strips are then clamped to the terminals, a mould placed around the joints, and molten lead poured into it.

The Electrolyte. Practice varies considerably as to the strength of solution to use. Chemically pure sulphuric acid is poured into water until its density becomes about 1.2, and then the mixture is allowed to cool before pouring it into the cells. The electrolyte *should completely cover* the plates. Cells for vehicle work use an electrolyte with density as high as 1.3. It is important to use perfectly pure acid and water, as impurities will cause local actions and ultimately destroy the plates.

It is well to remember that *water should never be poured into sulphuric acid,* as it is likely to cause the liquid to be thrown out violently.

The advantage of a strong solution is its lower resistance; but it is likely to produce the very objectionable effect of *sulphating.*

The density of the electrolyte falls immediately after filling a cell, since some of the acid is taken up by the plates; but it rises again in charging—for example, from 1.17 to 1.2. It is convenient to keep a hydrometer in several cells to observe the density of the electrolyte, not only at the beginning, but as a permanent indicator of the amount of charge and general working conditions.

The hydrometer is an instrument for determining the specific gravity of a liquid, and consists of a weighted bulb and an upright glass rod, bearing a scale, the unit point being fixed by the distance to which it sinks in pure water at 4°C. Readings above this point are for solutions of lower specific gravity than water, and those below it are for solutions of a higher specific gravity. For storage battery work, the specific gravity of the electrolyte is always between 1.1 and 1.3; hence we require only a certain portion of the scale as represented in Fig. 13.

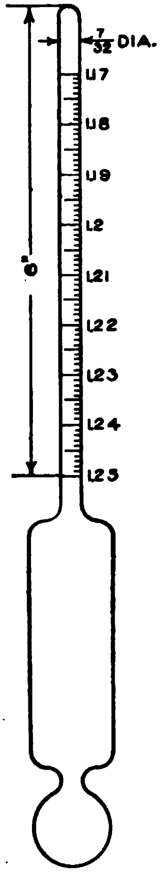
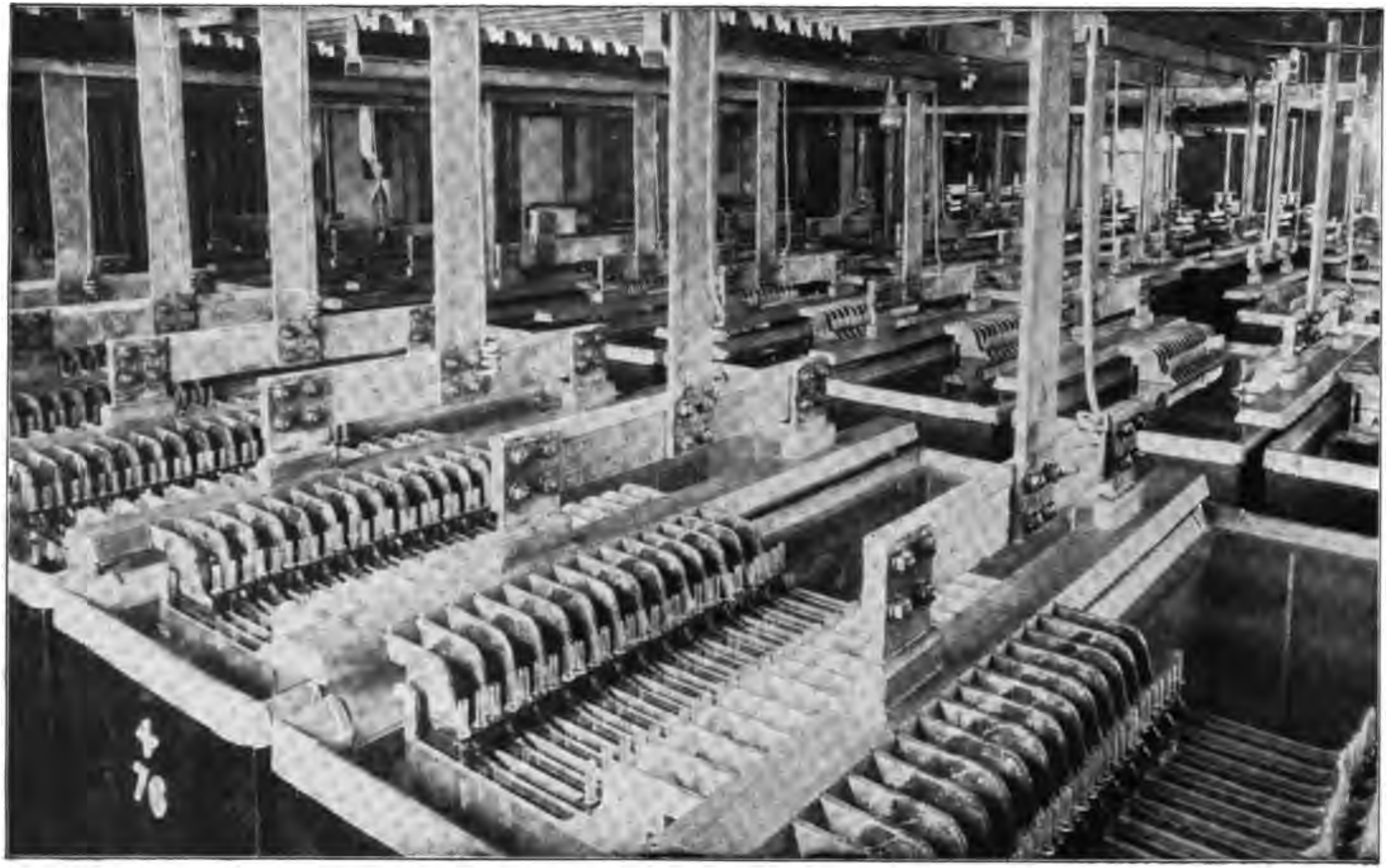


Fig. 13.
Hydrometer.

Charging. The charging should begin immediately after a new cell is filled with the electrolyte; otherwise the plates are likely to become sulphated. The first charge differs from subsequent regular charges in that it should be at a rate (lower than normal) that will not cause the temperature of the cell to reach 100°F.; but in all other respects it is the same.

Indications of Amount of Chargė in a Storage Battery. There are various methods of ascertaining the amount of charge in a storage battery. The following are the indications that will serve the purpose:

1. The E. M. F. rises from 2.1 volts, at the beginning of the charging of a lead cell, after it has been discharged, to approximately 2.5 volts when fully charged, although this value may be made a trifle higher or lower, depending upon the rate of charge and temperature of cell. The rise is quite gradual, but more rapid near the beginning and end of the charge, as indicated in Fig. 14. When the cell is fully charged, the E. M. F. becomes constant, and the curve approaches a horizontal line as shown. The charging should then be stopped, as any more energy passed through the cell is simply wasted in producing gases. The external voltage is higher in charging than in discharging, because of the internal resistance of the cell and resulting IR drop, which must be overcome in charging.



Large Storage Battery Installation

St. Paul Gas Light Company

The measurements of voltage should always be made when the current is flowing either in charging or discharging.

The E. M. F. on open circuit has little practical significance, since a cell, no matter how low it may have been discharged, will show about 2.1 volts after standing on open circuit a short while.

2. *If a record is kept* of the exact number of ampere-hours of charge and discharge, the actual amount of energy in the battery at any time is known, due allowance being made for leakage and other losses. For this purpose any integrating instrument, such as the Thompson recording wattmeter, may be used.

3. *The density of the electrolyte* gradually rises during the charging operation (Fig. 14), the density when charged being about .025 higher than when discharged. There is a lag in the change of the density of the electrolyte, the acid not being absorbed or given off at once by the plates; hence a little time should be allowed before taking any hydrometer reading as final. It is also advisable

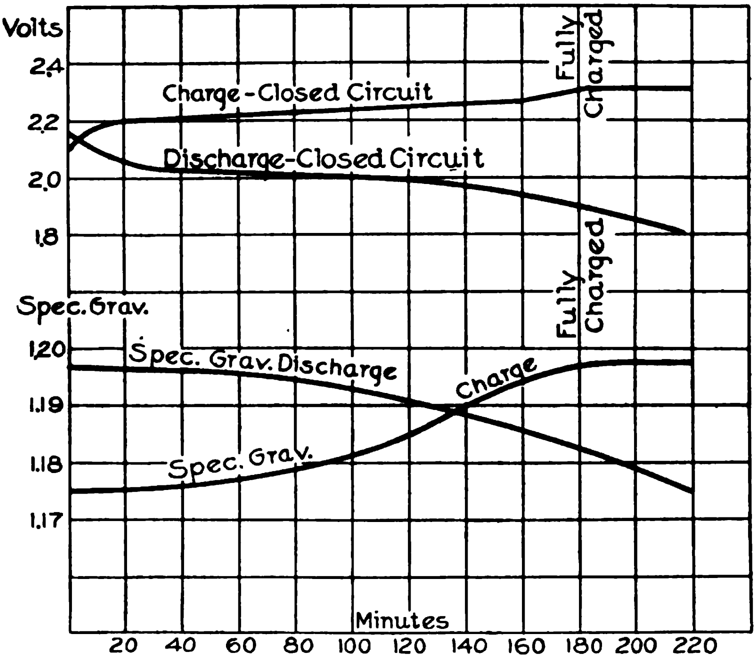


Fig. 14. Curves Showing Variations in Specific Gravity and Voltage in a Storage Battery during Charge.

to agitate the electrolyte to insure complete diffusion, as the electrolyte at the bottom of the cell is otherwise denser than at the top.

4. *Bubbles of gas are given off* freely when the battery is fully charged, since the material of the plates is then no longer able to take up the oxygen and hydrogen which tend to be set free by the electrolysis; these bubbles give the electrolyte the appearance of boiling, and often they are so fine that the liquid looks almost milky white, particularly in a cell which has not been very long in use.

5. *The color of the positive plates* varies from a light brown on active parts to a chocolate color when fully charged, and to nearly black when overcharged. The negatives vary from pale to dark slate color, but they always differ in color from the positives. This indication of the amount of charge is acquired by experience, but is quite definite after one becomes familiar with a particular battery.

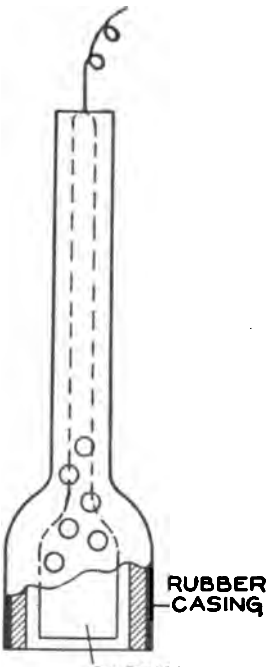


Fig. 15. Cadmium Test-Piece.

6. *Cadmium Test.* The apparatus for making this test consists of a small piece of cadmium, say $\frac{5}{8}$ by $\frac{5}{8}$ by $\frac{1}{32}$ inch, contained in a perforated hard rubber casing (shown in Fig. 15), the rubber covering being employed to prevent short-circuiting of the cell during the test (see Fig. 15). A rubber sleeve contains the conducting wire, wax being used to protect the soldered joint of copper and cadmium. Cadmium is used because it will give reliable readings of the E. M. F. of the positive and the negative plates, with respect to itself. In this way a relative condition of the battery and also of each plate can be determined.

With normal conditions of cell, when fully charged and in open circuit, the difference of potential between the positive and the cadmium piece immersed in the liquid is 2.5 volts or nearly so, and between the cadmium and the negative plates is zero or nearly so. In fact it is sufficient if the sum of the readings is about 2.5 volts.

To avoid false conclusions in making a cadmium test, hydrometer, temperature, and charge data should be noted. The cadmium test is usually made by inserting the tester at the center of the cell to get a uniform current distribution. This test gives readings the sum of which is less than 2.50 volts, when hydrometer tests, temperature, and charge data show that the cell is not fully charged. If the hydrometer, temperature, and other data show the charge to be completed, and the cadmium test gives .1 volt or more below 2.5 volts, one or more plates are defective and may be found by individual cadmium readings. For example, suppose we have a cell in which all the other conditions tend to show full charge, but the potential difference is low. A cadmium test is made; and the set of plates which shows the falling off from normal reading is the defective one, and should be examined for some of the troubles that will be discussed later.

In some cases the cadmium reading with respect to both positive and negative plates may approach zero; this is caused by a short circuit in the cell, which should be found and removed immediately.

In practice it is advisable to have the cadmium wet before the test is made, as the readings increase when cadmium is first placed in the electrolyte. The simplest way to accomplish this is to keep the cadmium tester in a beaker of distilled water when not in use. All foreign matter should be carefully removed from the cadmium, as it might affect the results. If gas bubbles collect on the cadmium, they should be taken off, as they tend to lower the readings.

The proper rate of charge depends upon the size and type of cell, and is usually specified by the manufacturer in each case, since it is merely an empirical fact, being determined by the construction of the plates.

The current for charging is ordinarily obtained from a direct-current dynamo, but any other direct-current source may be employed. The potential required for charging must exceed that of the battery, which, during the operation, acts as a counter-E. M. F., the expression being $I = \frac{P-e}{R}$, in which I is the current, P the potential applied to battery terminals, e the counter-E. M. F., and R the internal resistance of the cell. Usually P is 5 to 10 per cent greater than e, in order to cause the necessary charging current to flow through the resistance R of the cell.

In practice, P is regulated until the required charging current I is obtained.

The above equation, put into form of $R = \frac{P-e}{I}$, enables the internal resistance R to be calculated; but, as this varies considerably with the temperature and with different states of charge, its exact value is not often considered.

Another form of the above equation, $e = P - IR$, shows that the true E. M. F. of the battery is less than the charging voltage by an amount equal to the product of the charging current and the internal resistance. Conversely, in discharging, the total E. M. F. of cell is greater than the difference of potential P between its terminals, by the same amount; that is, $e = P - IR$. Hence it is necessary to know I and R, in order to find the real E. M. F. of cell. This applies to each individual cell, as well as to the entire battery, and is important in determining the amount of charge or working condition of a particular cell.

If the charging voltage P be kept constant, it is evident from the above equations that the current I will gradually decrease, since the C. E. M. F. or e of the cell steadily rises as shown in Fig. 16. This effect is counteracted somewhat by the fact that the internal resistance R also diminishes, owing to the density of the electrolyte increasing. This gradual reduction in the strength of the charging current is considered desirable by some authorities, since it enables the cell to take a greater charge than if the current were maintained

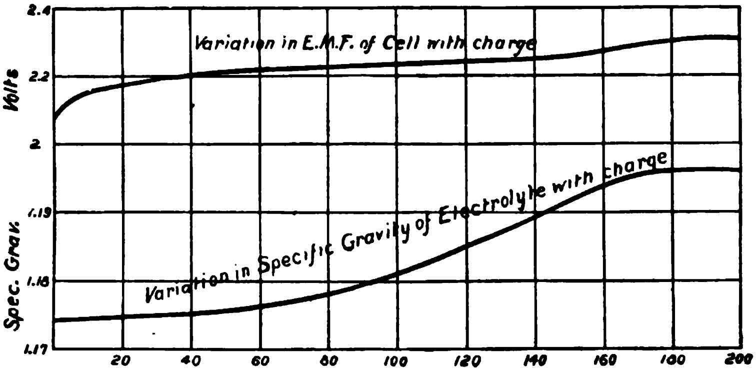


Fig. 16. Curve Showing Increase of E. M. F. in a Charging Cell.

at full strength. On the other hand, this diminishing charge makes it difficult to keep account of the exact number of ampere-hours supplied to the cell; hence, in ordinary commercial work, it is considered simpler to charge with a constant current, and if it is desired to keep the cell temperature down, the current is decreased near the end of the charge. The charging operation may be continued until the battery is fully charged as shown by the indications already stated. Since most types of cells are not injured by a slight overcharging at a moderate rate, it may even be carried a little beyond the charged point, as it tends to remove sulphating. A considerable overcharge should be avoided, as it causes excessive formation of gas bubbles in the active materials and is likely to heat the cell and even to cause disintegration and buckling of the plates.

Discharging. A storage battery is in most cases discharged within a few hours after being charged, as, for example, in electric lighting, when the engine and dynamo are run during the day for charging the battery which supplies current to the lamps during the night. But a portable battery for feeding lamps or a vehicle battery might be required to retain its charge for several days. The loss of charge in any battery standing on open circuit is about 25 per cent in one week, but for one day or less it is quite small.

Even when the discharge occurs immediately, the average voltage and the ampere-hours obtained are less than for the charge, as explained under "Efficiency." The loss referred to is additional, depending upon the time.

The operation of discharging is naturally the converse of charging, the changes which have been described as occurring in the latter take place also in the former, but in the reverse order. The normal rate of discharging is usually equal to that of charging, but may be somewhat greater. In some cases it is necessary to discharge at higher rates; but, by so doing, a percentage of the capacity in ampere-hours is sacrificed.

For example, a cell whose normal or eight-hour discharge rate is 100 amperes, can easily be discharged at 400 amperes for one hour, but only 50 per cent of the cell's capacity in ampere-hours is obtained at the latter rate. Under these latter conditions, there is not a large loss of energy, as is shown by the fact that to recharge a cell thus discharged requires only about 50 per cent of the normal charge.

TABLE VI

Percentage of Capacity Variation at Different Discharge Rates

Rate in Hours	Percentage of Capacity at 8-Hour Rate		
	Planté	Planté (+) Faure (−)	Faure
8	100	100	100
7	99	97	96
6	96½	93½	92
5	93	89	86
4	88	83	80
3	80	75	72
2	70	65	61
1	55	50	40

An excessive discharge rate is injurious to most types of storage-battery plates, since it tends to disintegrate the plates, and abnormally heats the electrolyte, which hastens the disintegration. It is therefore advisable to protect the battery with fuses or a circuit-breaker.

A storage battery *should never be discharged completely,* as it is very likely to become sulphated or otherwise injured; and moreover the voltage falls so rapidly towards the end of discharge that the current would be of no practical value. The limit of discharge is usually considered to be the point at which the voltage drops to 1.75, though when cells are used at the one-hour rate the limit of discharge is 1.6 volts.

A battery should never be allowed to stand in a discharged condition, but should be recharged immediately.

The charge usually left in a storage battery is from 10 to 30 per cent of the total capacity, depending on the rate of discharge; but this involves no considerable loss of energy or efficiency, since it remains in the battery each time, and the charging begins at that point.

Efficiency of Storage Batteries. The efficiency of any apparatus is the ratio between output and input. In a storage battery it is the ratio of the amount of discharge to what is required to bring the battery back to its original condition after a discharge.

The *ampere efficiency*—or, more properly, the *ampere-hour efficiency*—which is the ratio of current in ampere-hours drawn from the battery to current in ampere-hours put into the battery, is quite different from the *watt-hour efficiency*. The latter is the *real efficiency* since it considers the energy, and includes the voltage as well as the ampere-hours. The former may be used either through ignorance or intention to give a false idea, since the ampere efficiency is often 15 per cent higher than the watt efficiency.

Another difficulty is the fact that it is possible to obtain an apparent efficiency of over 100 per cent from a storage battery. Since a certain amount (about 25 per cent) of charge is always left in the cell, it is possible to draw more ampere-hours than were put in during the last charge, by simply discharging the cell more than usual.

This matter has been investigated by Ayrton, who says:

> "If an E. P. S. accumulator be over and over again carried around the cycle of being charged up to 2.4 volts, and discharged down to 1.8 per cell, the charging and discharging currents being the maximum allowed by the makers—namely, .026 ampere per square inch of surface in charging, and .029 ampere per square inch in discharging—the working efficiency thus obtained may be 97 per cent for the ampere-hours, and 87 per cent for the watt-hours. If, on the contrary, the cell be constantly charged up before being tested, then for the first few charges and discharges between the above limits, and with the same current density in charging and discharging, even the energy efficiency may be as high as 93 per cent; whereas, if the accumulator has been left for some weeks, then, although it was left charged, the energy efficiency for the first few charges and discharges will be as low as 70 per cent."

In general practice it has been found that the watt-hour efficiency of storage-battery plants, when in good condition, varies from 75 to 80 per cent. For instance, referring to the battery plant at the Edison Electric Company station in Boston, a series of tests made there show the battery installation to have an efficiency of 75 per cent.

Depreciation of Accumulators. The depreciation is claimed to be as low as 4 or 5 per cent per annum; but 7 per cent is a safer allowance to cover depreciation and renewals extending over long periods of time. During the first few years the depreciation may be practically nothing; but after five or ten years it will be considerable. These statements apply to *stationary* batteries in central stations or isolated plants. For *traction* or *automobile* service, which is much more severe, the life of storage batteries in some instances has not exceeded six months; and 3,000 to 5,000 miles total run is considered a good result in actual practice. For either stationary or vehicle storage batteries, the life of the positive plates is only half as great as that of the negatives. The figures given are based upon an average of the two.

It has been the practice of several storage battery manufacturers to insure their stationary battery equipments for 6 per cent per annum of their first total cost. This insurance is a maintenance contract calling for inspection and any repairs necessitated through normal use of cells.

TROUBLES AND REMEDIES

The most serious troubles which occur in storage batteries are *sulphating*, *buckling*, *disintegrating*, and *short-circuiting* of the plates. These can usually be avoided, or cured by proper treatment if they have not gone too far.

Sulphating. The normal chemical reaction which takes place in storage batteries is supposed to produce lead sulphate ($PbSO_4$) on both plates when they are discharged, their color being usually brown and gray, as already stated. But under certain circumstances a whitish scale forms on the plates, probably consisting of $Pb_2 SO_5$. Plates thus coated are said to be *sulphated*. This term is therefore somewhat ambiguous, since the formation of a certain proportion of ordinary lead sulphate ($PbSO_4$) is perfectly legitimate; but the word has acquired a special significance in this connection.

A plate is inactive, and practically incapable of being charged, when it is covered with this white coating or sulphate, which is a non-conductor.

The conditions under which this objectionable sulphating is likely to occur are as follows:

(*a*) A storage battery may be overdischarged—that is, run below the limits of voltage specified—and left in that condition for several hours.

(*b*) A storage battery may be left discharged for some time, even though these limits have not been exceeded.

(*c*) The electrolyte may be too strong.

(*d*) The electrolyte may be too hot (above 125° F.).

(*e*) A short circuit may cause sulphating, because the cell becomes discharged (on open circuit), and, when charging, it receives only a low charge compared with the other cells of the series. A battery may become overdischarged or remain discharged a long time, on account of leakage of current due to defective insulation of the cells or circuit; or the plates may become short-circuited by particles of the active material or foreign substances falling between them.

Sulphating may be removed by carefully scraping the plates. The faulty cells should then be charged at a low rate (about one-half normal) for a long period. In this way, by fully charging and only partially discharging the cells for a number of times, the unhealthy sulphate is gradually eliminated. When the cells are only slightly sulphated, the latter treatment is sufficient without scraping; when the cells are very badly sulphated, the charge should be at about one-quarter the normal rate for three days.

Adding to the electrolyte a small quantity of sodium sulphate, or carbonate, which latter is immediately converted into sodium sulphate, tends to hasten the cure of sulphated plates by decomposing or dissolving the unhealthy sulphate. This is not often used in practice, as a cell must be emptied and thoroughly washed, and fresh electrolyte added after the plates have been restored to their proper condition, before the cell can be used to advantage.

Sulphating not only reduces the capacity of lead storage batteries, but also uses up the active material by forming a scale which falls off or has to be removed. It also produces the following troubles:

Buckling. Buckling or warping of a plate, is caused by uneven action on the two surfaces; for example, a patch of white sulphate on one side of a plate will prevent the action from taking place there, so that the expansion and contraction of the active material on the other side, which occurs in normal working, will cause the plate to buckle. This might be so serious that it would be impossible to straighten the plate without breaking or cracking it; but, if taken in time, this may be accomplished by placing the warped plate between boards, and subjecting it to pressure in a screw or lever press. Striking the plate is objectionable, because it cracks or loosens the active material; but, if it should be necessary to straighten a plate in this way, a wooden mallet should be used very carefully, with flat boards laid under and over the plate. Buckling may be caused by an excessive rate of charging or discharging, as well as by sulphating.

Disintegration. Some of the material may become loosened or entirely separated from the plates, as a result of various causes.

The chief of these is sulphating, which forms scales or blisters that are likely to fall off, thus gradually reducing the amount of active material and the capacity of the cell. Buckling also tends to disintegrate the plates. Contraction and expansion of the active material take place in normal working, and are increased by excessive rates or limits of charging and discharging. This constitutes another cause of disintegration, particularly in plates of the Faure type containing plugs or pellets of lead or lead oxide paste.

The fragments which fall from the plates not only involve a loss of material, but are also likely to extend across or gather between the plates, and cause a short circuit.

The positive plates are far more susceptible to and injured by these troubles than the negatives. The former are also more expensive to make; therefore it is to them that special attention should be directed in the management of storage batteries.

Short-Circuiting. Short-circuiting of a cell may be caused by conditions previously stated, and also by the collection of sediment at the bottom of the containing cell. The short-circuiting caused by the dropping in of foreign matter, or the bridging of the active materials, is prevented by the use of glass, rubber, or wooden separators.

The short-circuiting of plates by the formation of sediment is prevented, or the chances of it are decreased, by raising the plates so that they clear the bottom of the containing cell. In small batteries this clearance is about an inch; in very large cells it is considerable, being about 6 inches; and large-sized plates, on account of their weight, are supported at the bottom by glass frames running lengthwise through the cell, as shown in Fig. 17.

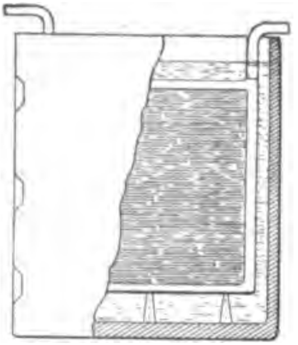


Fig. 17. Glass Frame Support Used to Prevent Short-Circuiting by Sediment.

This sediment should be watched carefully; and when it reaches a depth of 1 inch or more at the center of the cells, it should be removed. The usual method is to take out the plates, siphon the electrolyte off carefully, and then flush out the tanks until all the sediment is removed. If siphoning cannot be resorted to because of the absence of drop, a pump may be used, either of glass or of the bronze rotary type.

Troubles from Acid Spray. A storage battery gives off occasional bubbles of gas at almost any time or condition; but when nearly charged, the evolution becomes more rapid. These bubbles, as they break at the surface, throw minute particles of acid into the air, forming a fine spray which floats about. This spray not only corrodes the metallic connections and fittings in the battery room, but is also very irritating to the throat and lungs, causing an extremely disagreeable cough.

Glass covers are sometimes placed over cells to prevent the escape of fumes; but this is not advisable, as the glass becomes moist and will collect dust, thus forming a conducting surface over the cell.

Attempts have been made to do away with this spraying by placing an oil film (thin layer of oil) over the electrolyte; but this has the objection of interfering with hydrometers; in addition, it sticks to the surface of the plates when they are removed, and interferes with their conductivity on replacing them.

Another plan consists in spreading a layer of finely granulated cork over the surface of the liquid; but while this does not interfere with the hydrometer, it makes the cell look dirty.

The general practice is to depend almost entirely upon ventilation to get rid of the acid fumes; in fact, even forced ventilation is used. A blower forces fresh air into the room, which is provided with a free exhaust.

In connecting up the cells, it is advisable to use lead-covered copper cables, and to paint all connections with an acid-resisting paint, as these coverings protect the copper and prevent the formation and the dropping of copper salts into the cell.

Purity of the Electrolyte. This is very important, and great care should be taken to insure it. The electrolyte may have nitric acid present when formed (Planté) plates are used; and some chlorine, when Chloride negatives are used. In addition, iron may be present, due to the water or acid if the sulphuric acid is made from iron pyrites; it may also be present owing to the corrosion of iron fittings near the cells, some of the scale falling into the electrolyte. Similarly, some of the copper salt formed from the connections by this corrosive action may fall into the cell. Mercury may also be present as a result of the breakage of hydrometers or thermometers.

Other foreign substances might be present, but those named are the most harmful. Nitric acid, even in exceedingly small quantities, will cause disintegration of plates, as the supporting material is destroyed. Chlorine has a similar effect. Iron, mercury, and copper produce local action, and thus decrease the efficiency and ultimately the life of the cells. The electrolyte should be tested about once a week for these impurities; and if any of them are present, it should be drawn off and renewed. If nitric acid is present, it is even advisable to flush the cell with pure water.

TESTS

1. **Test for Chlorine.** Take a sample of the electrolyte, acidulate with nitric acid, and add a few drops of silver nitrate solution. If a curdy white precipitate forms, which is soluble in ammonium hydrate, chlorine is present in some of its compounds.

2. **Test for Iron.** Iron may appear in one of two forms, namely, ferrous or ferric salts. A small sample is taken, and some concentrated hydrochloric acid added, and then some potassium ferric cyanide; if a heavy blue precipitate forms, ferrous iron is present; if in very minute quantities, a deep blue-green discoloration results.

3. **Test for Ferric Salts.** To a sample of the electrolyte, add some hydrochloric acid and a few drops of ammonium thiocyanite; if a blood-red solution or precipitate is the result, ferric salts are present.

4. **Test for Copper.** To a sample of electrolyte, an excess of ammonium hydrate is added; if a rich blue solution is the result, copper is present. It is advisable to check the test by taking another sample and adding some potassium hydrate to it; if a blue precipitate is found which turns black upon boiling, it is additional proof of the presence of copper.

5. **Nitric Acid or its Compounds.** As these are injurious, even in very small quantities, it is advisable to make the following test, which is very sensitive: Some diphenylamine in concentrated sulphuric acid is added to the sample; if a deep blue color is the result, nitrates or nitrites are present.

6. **Test for Mercury.** Mercury may be present in two forms, mercurous or mercuric compounds. The *mercurous* compounds give a black precipitate with lime water, and a greenish precipitate with potassium iodide. The *mercuric* compounds give a yellow precipitate with lime water, and a red or scarlet precipitate with potassium iodide.

On account of possible difficulties with these various impurities, the following are recommended:

1. Test every carboy of sulphuric acid before using.
2. Concentrated sulphuric acid should not be kept around, as it may be used by mistake, which would ruin the plates.
3. Only distilled water from carboys should be used, and not from barrels, as in the latter case it may be contaminated by organic matter.
4. Water from the city mains is never to be used unless the amount of impurities which it contains is very small.
5. When testing with hydrometer for specific gravity, the battery should be fully charged, and tests *always made at the same temperature, or temperature changes should be corrected for,* because the specific gravity of the electrolyte falls with increase of temperature. The specific gravity changes due to temperature are given in Table VII.

TABLE VII

Specific Gravity of Dilute Sulphuric Acid at Various Temperatures

TEMPERATURES	30° F.	40° F.	50° F.	60° F.	70° F.	80° F.	90° F.	100° F.	110° F.
Sp. gr.	1.1593	1.1562	1.1531	1.1500	1.1469	1.1438	1.1407	1.1376	1.1345
"	1.2096	1.2064	1.2032	1.2000	1.1968	1.1936	1.1904	1.1872	1.1840
"	1.2620	1.2590	1.2530	1.2500	1.2470	1.2440	1.2410	1.2380	1.2350
"	1.3090	1.3060	1.3030	1.3000	1.2990	1.2940	1.2910	1.2880	1.2850
"	1.3620	1.3580	1.3540	1.3500	1.3460	1.3420	1.3380	1.3340	1.3300
"	1.4144	1.4076	1.4048	1.4000	1.3952	1.3904	1.3856	1.3808	1.3768

Putting the Battery out of Commission. If, for any reason, the battery is to be but occasionally used, or the discharge is to be at a very low rate, a weekly freshening charge to full capacity at normal rate should be given.

It frequently happens in practice that a storage battery equipment is put out of commission for a lengthy period (for instance, in most summer or winter resorts, the battery may be used for one-half of the year only). In such cases the procedure is as follows: First give the battery a complete charge at normal rate, then siphon off the electrolyte into carefully cleaned carboys (as it may be used again); and, as each cell is emptied, *immediately* refill it with pure water, to prevent the charged negative from heating in the air, as this would result in loss of capacity. When the acid has been drawn from all cells and replaced with water, begin discharging the battery, and continue until the voltage falls to or below one volt per cell at normal load (rate); when this point has been reached, the water should be drawn off. In this condition the battery may stand without further attention until it is to be put again into service; and to do this, proceed in the same manner as when the battery was originally put into use.

If, during discharge, when water has replaced electrolyte, the battery shows a tendency to get hot (100°F.), add colder water.

COMMERCIAL APPLICATIONS

The function of a storage battery is to receive electrical energy at one time or place, and to give it out at some other time or place. The principal uses are the following:

1. To furnish portable electrical apparatus with power.
2. To make up for fluctuations, and thus steady the voltage and load on the generator.
3. To furnish energy during certain hours of the day or night, and enable the generating machinery to be stopped.
4. To aid the generating plant in carrying the maximum load (peak), which usually exists for only an hour or two.
5. To make the load on engines or prime movers more uniform, by charging the battery when the load is light.
6. To transform from a higher to a lower potential by charging the cells in series, and discharging them in parallel, or *vice-versa*.
7. To subdivide the voltage, and enable a three- or a five-wire system to be operated from a single generator.
8. To supply current from local centers or substations.
9. To supply current to electrically-driven vehicles.
10. As sources of current in telephone and telegraph systems.
11. For car-lighting purposes.
12. As sources of constant potential and current in electrical laboratories.

Portable Storage Batteries. The storage or the primary battery is practically the only means of supply for portable electric lamps or for those not connected to a dynamo even when they are not portable.

The various manufacturers furnish portable forms of storage batteries. The Gould Storage Battery Company's portable battery

(Fig. 18) is arranged in a case made as a hard rubber jar, lead-lined box, or glazed earthenware jar, over which is placed a rubber gasket, and then a wooden cover clamped in place by U-shaped straps passing around the containing vessel. For ventilation in charging, the cover has threaded holes, which, when the battery is in use, are closed with hard rubber stoppers. The usual number of cells in a case is from one to five, although they are made up in larger numbers if desired. The batteries are rated at 2 volts per cell.

A serious objection to portable storage batteries is their great weight. For example, a standard size weighing 100 lbs. yields 5 amperes at ten volts, or fifty watts, for ten hours—just enough to feed a 16-candle-power lamp. The total discharge is 500 watt-hours or two-thirds of one horse-power-hour. The special forms of battery used in automobiles give about twice this output for the same weight.

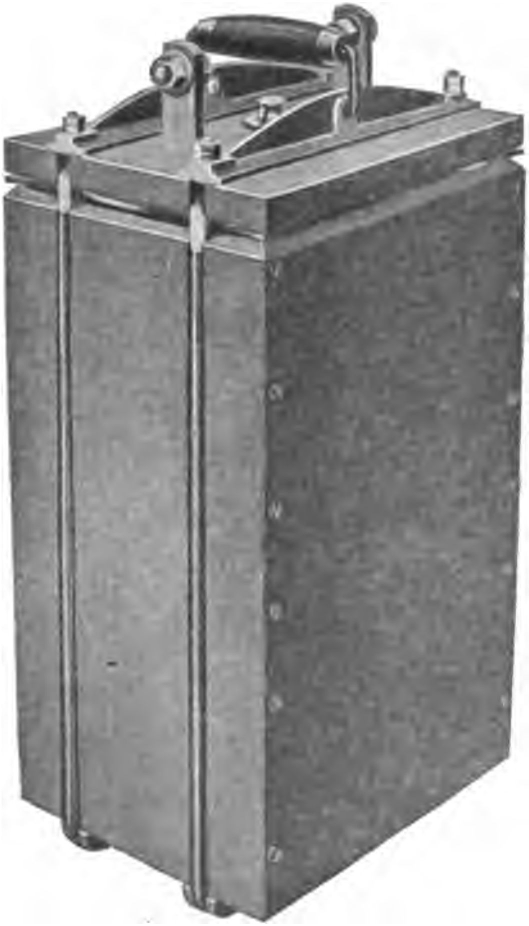


Fig. 18. Gould Portable Storage Battery.

This weight is almost prohibitive to portability, except for automobiles, railway train lighting, and special purposes.

Portable batteries, for example, are used for feeding small motors, lamps, etc., for medical or dental purposes, in which cases their weight is not a serious difficulty, in view of the importance of the work and the small amount of energy required. Another special field for very small batteries is the theatrical application, for which they are carried by performers. Storage batteries are also extensively used as sources of power to drive small fan and kinetoscope motors.

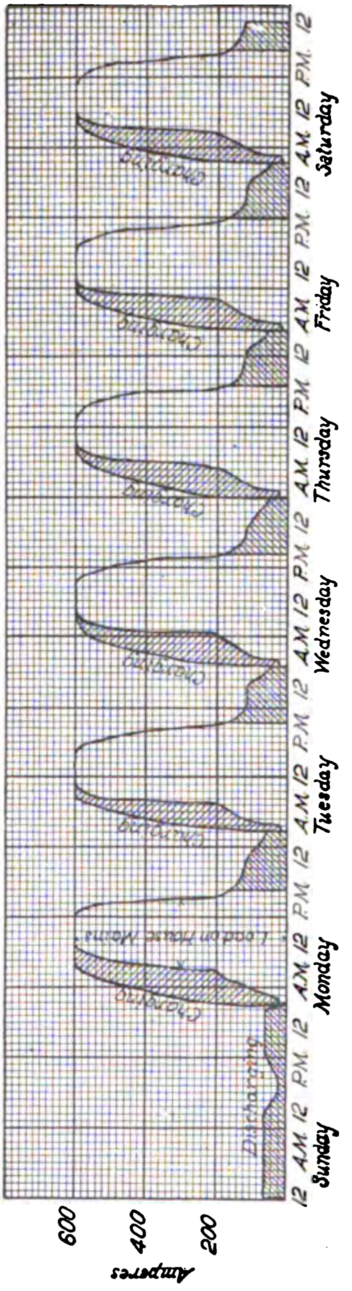
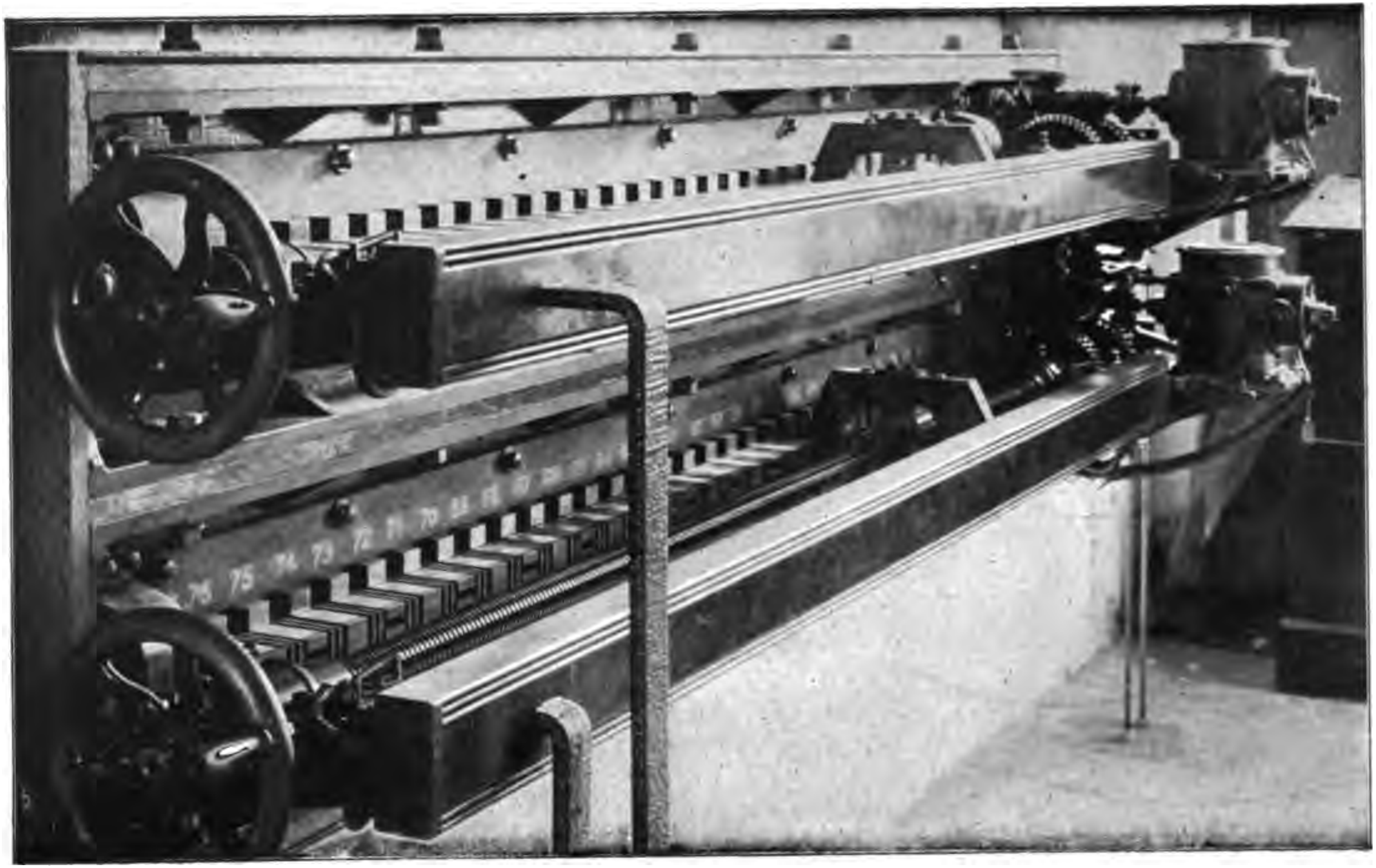


Fig. 19. Load Curve of Astor Building, New York City.

Storage Batteries for Preventing Fluctuations due to unsteadiness in the driving power or in the load, as with elevators, are often applied successfully. A dynamo driven by a gas engine for example, may vary periodically in speed because of the explosive action of the gas in the cylinder; and a battery connected in parallel with the dynamo will have the effect of steadying the voltage. A storage battery is generally installed in connection with a small gas-engine or steam-engine lighting plant, to enable the engine to be stopped for a considerable portion of the time, and thus save labor and attention, in which case the battery may also act to prevent fluctuations. A windmill electric-lighting plant must have an accumulator or some other means of storing



End Cell Regulating Switches

Minneapolis General Electric Company

energy, not only to eliminate fluctuations in speed, which are continually occurring, but also to bridge over the considerable periods of calm weather.

To Furnish Energy during Certain Portions of the Day or Night. In almost every electric-lighting plant, there are long periods during the day and late at night when the number of lamps lighted is so small that it may not pay to run the generating machinery.

For example, Fig. 19 is a load diagram showing the weekly output of the electric plant of the Astor Building in New York City. The generator plant runs from 3 a.m. to 8 p.m. each day, the battery being charged from 3 a.m. to 11 a.m.; and when the generating plant is shut down at 8 p.m. the battery carries the entire load from then until 3 a.m., when the plant is started up again. Saturday nights the plant is shut down at eight o'clock, and the battery furnishes all the power required from then until Monday morning at 3. This enables the plant to be operated by two gangs or shifts, practically no labor being required for the remaining seven hours, as the battery carries the load, and the machinery is stopped entirely all day Sunday, giving a stretch of thirty-one hours once a week, and seven hours each night for cleaning and repairs. In a hotel or residence, or on board a yacht, it may be desirable to stop the machinery and avoid the vibration and noise during the night.

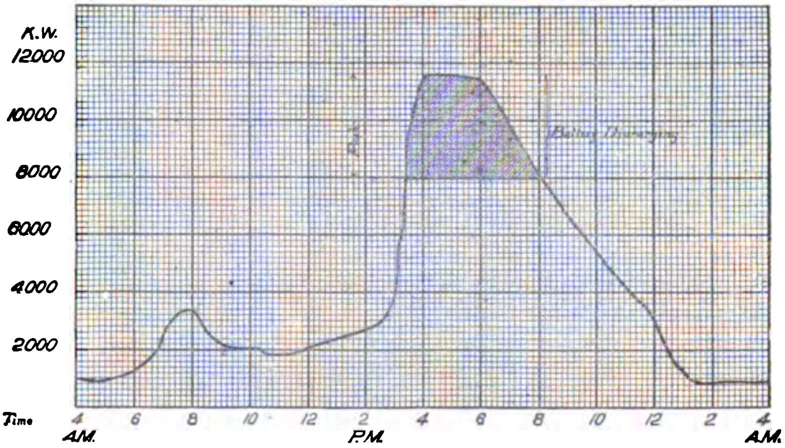


Fig. 20. Load Curve Showing "Peak" of Load Carried by Storage Battery.

Storage Batteries to Aid in Carrying the Maximum Load. Assume, in the case of the load diagram shown in Fig. 20, that the generating machinery is capable of supplying 8,000 kilowatts, and that a storage battery is used to furnish the remaining 3,600 kilowatts at the time of maximum load—that is, the *peak* of the load diagram. This simply means that batteries are substituted for a certain portion of the machinery plant, and the question is whether or not the substitution is of any advantage.

The first cost of a battery for a given rate of output depends simply upon the time of discharge. Batteries usually have a normal period of discharge of about 8 hours, at which rate the price of accumulators to furnish a given number of watts would be 3 to 5 times as great as that of the equivalent boilers, engines, and dynamos combined; but if the time of discharge is reduced to about 2 or 3 hours, the costs are about equal; and with a still higher rate, the cost of batteries would be less.

As a matter of fact, the storage battery secures other advantages, so that the total gain may be very important. For example, there is a reserve supply in case of accident; and the load may be made more uniform, as will now be explained.

Storage Batteries to Maintain Uniform Loads on Engines. Steam engines are very inefficient at light loads, and this fact often causes serious losses, especially in electric-lighting plants. Judicious selection of the number and sizes of the engines enables them to be worked in most cases at a considerable fraction of their full capacity nearly all the time. Nevertheless the storage battery gives greater flexibility to the plant, and renders it easy to increase the economy of the engines by making their loads still more uniform and nearer to their full capacities while they are running. The engines can be made to have a uniform full load, the battery being charged when the external load is light, and the battery taking the peak of the load when it is heavy.

Storage Batteries Used as Transformers. If the cells of a battery are arranged in series while being charged, and in parallel for discharging, a high voltage will be required for charging, and a low voltage will be given out. The amounts of energy measured in watt-hours are the same, less the loss of about 25 per cent which always occurs in accumulators; the result is similar to that obtained by an alternating-current transformer or motor-dynamo, but is less efficient. As an example, the equipment used at the Brooklyn Navy

Yard may be mentioned. It consists of about 250 small cells connected up in series parallel of 5 sets of 50 cells each and charged on a 110-volt circuit. When discharged, they are connected up all in series, and give about 500 volts, but with very small current. This equipment is used to furnish 500 volts for the *insulation test* of cables, and therefore requires little or no current.

Storage Batteries Used for Subdividing Voltage. The most important practical case is that in which a dynamo of 220 volts charges a battery of corresponding potential, a three-wire system being supplied from the battery, the neutral wire of which is connected to the middle point of the battery, as represented in Fig. 21.

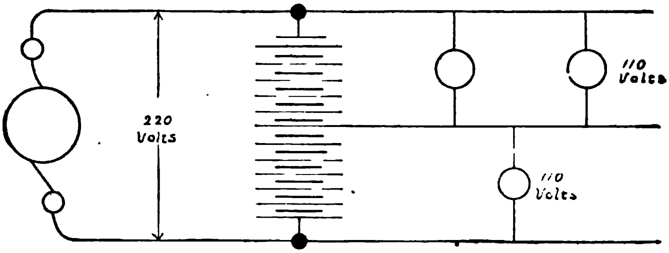


Fig. 21. Battery Used to Subdivide Voltage.

This arrangement avoids the necessity of running two dynamos, and allows the battery to be placed in a substation near the district to be supplied, so that it is necessary to run only two conductors to that point instead of three. The same principle may be applied to the five-wire system. When used in this manner, each side of the system requires its individual end cells and regulators.

The Hartford Electric Light Company was one of the first in this country to introduce the modern method of high-tension transmission, with low-tension 3-wire distribution.

The auxiliary battery used in connection with this equipment consists of 130 Chloride accumulators (65 on a side), each cell containing 31 negatives and 30 positive plates, each 15½ by 31 inches, placed in lead-lined tanks measuring 58¼ by 21½ by 43⅞ inches. Fig. 22 is a diagram showing the general plan of the system. The power is transmitted 10.8 miles from the Farmington River Power Station to the Pearl Street Station, in Hartford, by means of step-up transformers, a 10,000-volt transmission line, and step-down transformers for distribution. From Pearl Street Station to State

Street, a distance of 3,000 feet, the current is transmitted at 2,400 volts, at which latter point, by means of step-down transformers and rotary converter, the storage battery is charged and the current distributed over a low-tension three-wire system.

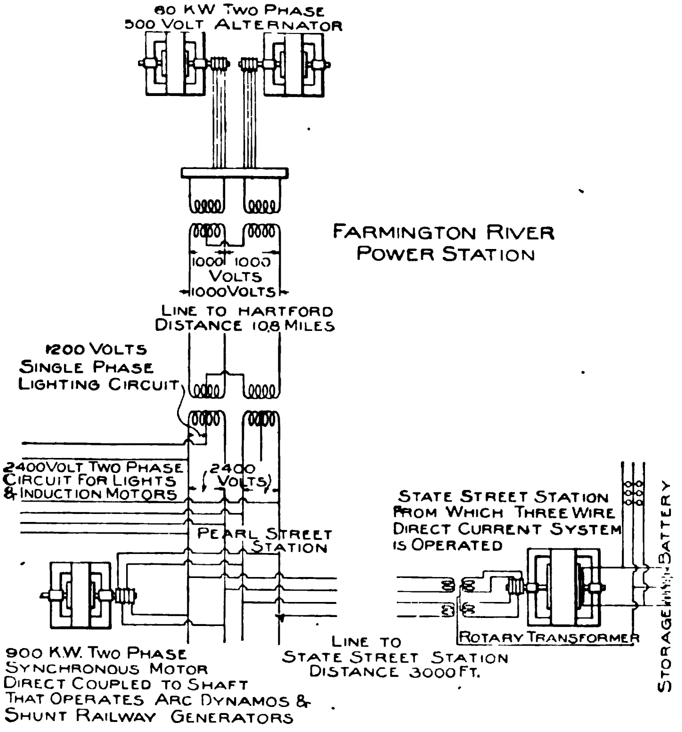


Fig. 22. Plan of Farmington River-Hartford Distribution System.

Storage Battery for Substations. The plan of installing battery plants at local centers, which are charged from the main station, enables some of the conductors to be saved in a three- or five-wire system, as already stated. It also makes it possible to reduce the size of these conductors, because the current which flows over them can be kept practically constant, so that it is not necessary to have them large enough to carry the maximum current consumed by the lamps, etc., which may be several times its average value. The generating machinery has the same steady load as if the battery were located near it.

The batteries at the various substations may be connected and charged in series or in parallel. The former plan would require far less copper in the conductors, since the voltage is multiplied by the number of batteries in series, and the current is the same as for a single battery. On the other hand, this great difference of potential would exist between the first and the last batteries of the series; and if either of these became grounded, any person connected to the earth and touching a wire supplied by the other battery would receive a shock due to the total voltage.

An excellent example of a storage battery substation is the Bowling Green Plant of the New York Edison Company. The Bowling Green Station furnishes an auxiliary supply of current directly from the battery, enabling the feeders, extended as tie-feeders into the Bowling Green building, to be used as distributing feeders to the system from both the Duane Street and Bowling Green Stations. While acting as an auxiliary supply to the general system, the battery also takes care of the distribution of current to the extensive installation in the Bowling Green building itself. The supply of current to charge the battery is taken from the Duane Street Station, about a mile distant, over four tie-feeders equipped with controllable disconnective switchboxes on the Bowker-Van Vleck system. This enables them to be used as tie-feeders by disconnecting them from the general system during the hours of light load, and as distributing feeders during the hours of maximum load, when they feed current into the system from each end. A considerable saving is thus effected in the investment, because costly feeders are not required to supply the maximum load to a distant part of the system.

This installation of an auxiliary source of current supply in the lower district makes it possible to shut down the generators in the Duane Street Station during the hours of minimum load, the supply of current to the district below 8th Street being derived from the battery plants at Bowling Green and 12th Street Stations, supplemented, if desired, by the supply of current from the 26th Street Station, over the tie-lines to 12th Street Station, whence the current is distributed through boosters raising it to the required potential, over the tie-feeders to the Duane Street Station switchboard. The battery and operating rooms of the Bowling Green

Station are located in the sub-basement of the Bowling Green Office Building. Vitrified hollow tile for conducting the feeder cables are laid under the battery-room floor, which consists of glazed white tile. Drains to carry off the water or acid run in the aisles between the cells, and lead to small cesspools which discharge into a lead drain-pipe.

The battery consists of 150 Chloride cells, 75 in series on each side of the three-wire system. The cells consist of wooden tanks, 40¾ by 21½ by 30½ inches, treated with an acid-proof paint and lead-lined, each containing 14 positive and 15 negative plates 15½ inches wide by 31 inches high. Each tank is supported on four petticoat porcelain insulators resting upon 6-inch glazed tiles.

The plates are suspended in the tanks by shoulders resting upon sheets of heavy glass, which stand upon lead saddles in the bottoms of the tanks. The cells are connected by welding the plate terminals to lead bus-bars, no mechanical connections being used.

Twenty of the end cells on each side of the system are used for regulating, being separately connected to contact points on the regulating switches, which carry movable contacts operated by a screw. The potential is raised or lowered by cutting in or cutting out the regulating cells. Two regulating switches are connected in multiple on the positive, and two on the negative, side, to permit of discharging at two potentials, or to enable the battery to be charged and discharged simultaneously. The conductors between each series of cells, and between the regulating cells and the regulating switches, consist of copper bars 3 inches wide by ½ inch thick. These bars are supported on porcelain insulators resting in hangers. The connections of this equipment are shown in Fig. 23.

The capacities of the battery at various rates of discharge are:

2,000 amperes per side for 1 hour.
1,000 amperes per side for 3 hours.
400 amperes per side for 8 hours.

Provision has been made in the battery-room, for the installation of a duplicate battery, which can be placed over the present plant. The booster is used to raise the voltage from that of the system to that required for charging the battery. The booster can be used also to raise the voltage of discharge for feeding some distant point of the system at a higher potential than would normally be required. The machine consists of one positive and one negative dynamo at each end of a common shaft driven by two motors. Each dynamo

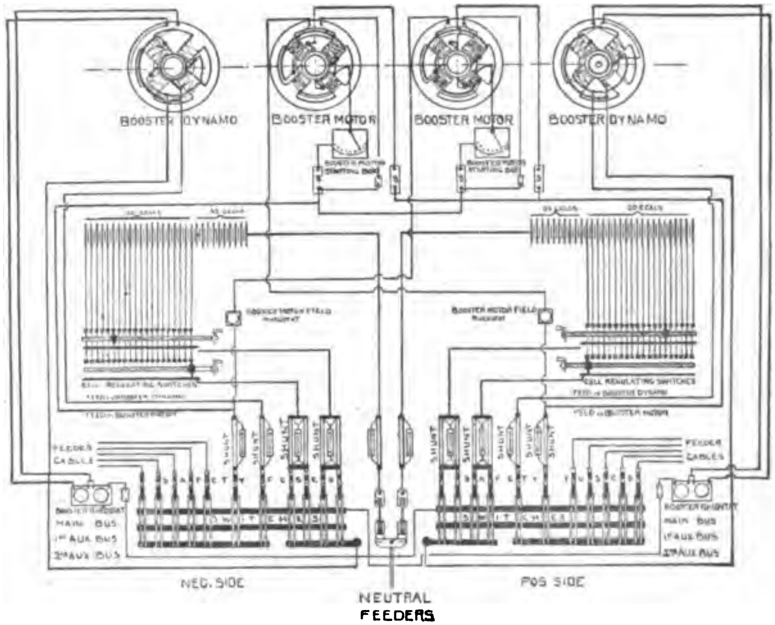


Fig. 23. Connections of the Bowling Green Storage Battery Substation.

has a capacity of 1,200 amperes, and a range of pressure up to 60 volts.

Storage Batteries Used for Two or More of the Above-Named Purposes. Each of the different uses has been considered separately to avoid confusion, but in most cases the storage battery is adopted in order to secure several advantages. By thus combining different applications, the plant is rendered not only more economical, but also more flexible. For example, the battery may be utilized to help out the generating machinery at times of heavy load, or when the latter is partially or wholly disabled. It often happens that it is difficult to produce or maintain sufficient steam pressure, owing to poor draft or other conditions, in which event a battery enables the boilers to be temporarily relieved of some or all of the drain upon them while the pressure is being raised to the proper point. It may also be necessary or desirable to shut down the machinery or a portion of it, temporarily, in order to make some repair or adjustment. It is also possible to feed some of the circuits from the battery while the others may be supplied at a higher or lower voltage by the machinery. In these and many other ways the storage battery may be a convenient adjunct to an electrical system. The fact that it is so radically different from the machinery in its nature and action, makes it very unlikely that the entire plant will be crippled at any one time, since the two sources of current are not exposed to the same dangers. An accident to the steam piping, for instance, might shut down all the machinery, but probably it would not affect the battery; and, *vice-versa*, an accident to the latter is not likely to extend to the former.

As an example of this application of the storage battery to several purposes, the following case may be cited:

The installation of storage batteries at the power house of the Woronoco Street Railway Company, in Westfield, Mass., presents features of special interest. After considering various methods of increasing the power-house capacity, rendered necessary by the construction of an extension of the line, it was decided that the storage battery offered the greatest advantages.

The station equipment consists of two 75-kilowatt multipolar generators belted to two 120-horse-power, high-speed, simple, non-condensing engines, steam being furnished by two 90-horse-power return tubular boilers.

The battery consists of 264 Chloride Accumulator cells, Type F–11, in glass jars of Type F–13, permitting an increase of 20 per cent by the addition of one pair of plates in each cell, and is installed in a small brick extension to the power house. The cells are located in one tier, each cell being supported on a sand tray resting on four glass insulators. The foundation for each row of cells consists of two stringers of wood suitably braced and supported on brick piers. This battery was not installed as a voltage regulator, the feeder system being so designed that the drop on the line is only a small amount.

By means of the battery, the load on the machinery is reduced within the capacity of one unit, leaving the second one as a reserve in case of an accident or an unusually heavy load. Without the battery, both machines would be needed nearly all the time.

The economy of operation due to using one unit instead of two, is clearly shown by the following station records:

	Date, 1899.	Lbs. coal.	Output kw.-hrs.	Lbs. coal. per kw.-hr.
With battery	Oct. 25–27	16,250	3,032	5.36
Without battery	Oct. 28	6,250	981	6.37

This shows an increase in the coal consumption, of 19 per cent, on the day when the operation of the battery was discontinued. The plant is also noteworthy from the fact that the station attendance is reduced to one man per shift, the engineer doing his own firing. This arrangement could not have been continued under the conditions of increased load, had it not been for the improved regulation and reduction of coal handling, and especially the increased reliability of operation secured by the battery.

On several occasions the battery has been called upon to carry the entire load of the system for an hour or so, during a temporary shut-down of the rest of the plant, as well as early in the morning or late at night, when only one or two cars are in operation.

Storage Batteries for Propelling Vehicles and Boats. The storage battery is usually about 35 per cent of the total weight in the modern electric automobile; and even with this great proportion, the distance run on one charge is seldom more than from 20 to 40 miles at a speed of about ten miles per hour, and that only on comparatively smooth roads. The ordinary battery equipment consists of about 44 cells of 108 ampere-hours capacity with an average discharge voltage of about 1.9.

In cities or where the roads are good, with charging stations close at hand, the electric automobile is superior to the gasoline types on account of the absence of explosive vapors, with the accompanying odor and noise. But for general touring they are not so handy, on account of the limited capacity of the battery.

The application of the storage battery to the street-car, while presenting such great advantages as the entire absence of poles and overhead wires, has not been a commercial success, mainly on account of the mechanical weakness of the plates, which are not able to stand the jolting and jarring or the rush of current due to frequent starts and stops. Another objectionable feature is the escape of acid fumes into the car, producing throat irritations and coughs among the passengers, although this is overcome by the use of fans.

The storage battery has been comparatively successful as a source of power in submarine boats, being charged while the vessel is on the surface, and discharged to run electric motors and lights when the vessel is manœuvering under the surface.

Storage Batteries in Telephone and Telegraph Systems. Since the adoption of the central battery systems by telephone companies, the use of the storage battery for this purpose has become very common, its advantages over the primary cell being as follows: Lower first cost; smaller space required (about ¼ of that occupied by an equivalent primary battery); greater constancy of E. M. F. and lower internal resistance; absence of the annoying *creeping salts;* and rapidity of recharge. The cost of storage-battery maintenance is about ⅛ that of the primary cell.

In telephone work, the battery is installed in the district station, and charged when the line is not in use, from either a street connection or a generator in the station. When the line is in use for conversation, the charging current is automatically cut off, and the battery alone switched into service.

The storage battery in telephone work has become so important that the following description of a typical installation is given.

In the Filbert Street Exchange of the Philadelphia Bell Telephone Company, there are two generating units, forming a duplicate plant, each consisting of one engine, directly connected to a 30-kilowatt, 110-volt dynamo. These machines are run on alternate days, and are used for lighting the building and for furnishing power at 110 volts to various motor-generators. The latter comprise two 1.5-kilowatt machines for charging a 20-volt battery, one 1.5-kilowatt machine for charging an 8-volt battery; one 500-watt machine for charging a 4-volt battery; and two ¼-horse-power 75-volt alternating-current motor-dynamos for ringing call bells. Only one machine is installed for the 8-volt battery, and one for the 4-volt battery. Both batteries are in duplicate. To avoid a possible breakdown, a rheostat is furnished, so that the batteries of lower voltage can be charged from batteries or motor-generators of higher voltage. All machines are protected by automatic cut-outs.

The 20-volt battery consists of ten Chloride Accumulators having a capacity of about 1,000 ampere-hours, which furnish all the current needed by the subscribers for talking and for calling up the central office. The 8-volt batteries, in duplicate, consist of four cells, each having a capacity of 2,400 ampere-hours. This battery furnishes current for the "disconnect" signals on the operator's cords, and for the relays which cut out the subscriber's lamp signal when the operator answers his call, by plugging into the jack corresponding to the lamp signal.

Half the drop in potential of the 8-volt battery is in the 4-volt lamp, and the other half in the cut-out relay. This battery is in duplicate, so that one can be charged while the other is being discharged. This avoids danger of burning out the lamps, as the voltage of the battery is raised from 8 to 10 volts during charging.

Each of the duplicate 4-volt batteries comprises six 13-cells arranged in two sets. One of these sets consists of four cells, two in series, two in multiple; the other of two cells. The two extra cells are needed on one of the batteries to supply current for the operator's transmitters. The latter is arranged to furnish a current of four volts or two volts as desired. The 4-volt battery also furnishes all current for the lamp signals, which light when a subscriber takes his telephone off the hook. This lamp is put out when the operator answers the call. This battery also is made in duplicate, one being charged while the other is discharged, to avoid burning out the lamp from the higher voltage during charge.

Storage Batteries for Train Illumination. When cars are lighted by oil or gas lamps, these, owing to their size, and the heat produced by them, can be installed only in certain places, so that the distribution of light is not general, besides which, the heat and odor given off by the lamps are objectionable. The inflammable character of the illuminants involves great danger of explosion or fire in case of a train wreck. The absence of these disagreeable and dangerous features in electric lighting, is what has made its application so desirable in traction work.

Several methods of electric illumination have been tried on railroad trains. In one of the simplest of these, a small dynamo on the locomotive truck, or one perched above the boiler, is driven by a small steam turbine. While this is an economical method, it has the objection, that when the locomotive is uncoupled, the cars must be illuminated by some other means.

For this reason, the storage-battery system of supply has been adopted. One of the most successful methods is the "Axle Light" system. This, as its name implies, derives the motive power for its dynamo from the car axle. The mechanism is suspended from the bottom of the car, and is completely encased, so as to be dust-proof and waterproof. It comprises a small dynamo driven from a pulley on the axle of the car by means of a friction coupling.

The dynamo and driving mechanism are shown in Fig. 24. The former generates from 32 to 40 volts, depending upon the speed of the train, provided that it exceeds 15 miles per hour, the dynamo being then automatically connected to the battery and lamp circuit. An automatic device rectifies the direction of current, so that even though the direction of rotation is reversed, the battery is always charged in the proper direction. A variable resistance in series with the field coils is automatically adjusted by a small motor, so that even at high speed the normal limit of voltage is not exceeded.

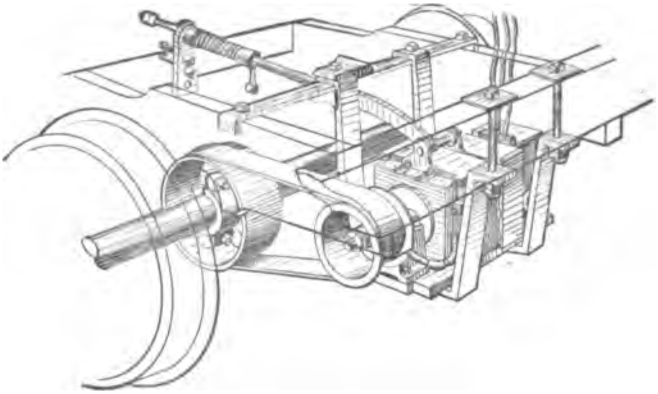


Fig. 24. Method of Suspension Used by the "Axle Light" System.

The lamps are 16-candle-power at 30 volts, the filaments being short and heavy so that they are not injured by vibration.

After the storage battery has been charged, it acts in parallel with the dynamo, and avoids fluctuations in voltage. When the car stops, the dynamo is automatically cut out, and the full supply of current is furnished by the battery, which is large enough for a ten-hour supply at full load.

Storage Batteries for Electrical Laboratories. The great advantage of this source of power in electrical laboratories, is the fact that any variation in the voltage is very gradual, and by the simple regulation of a rheostat in series with the battery, the operator can keep his voltage and current absolutely constant while a test or calibration is being made.

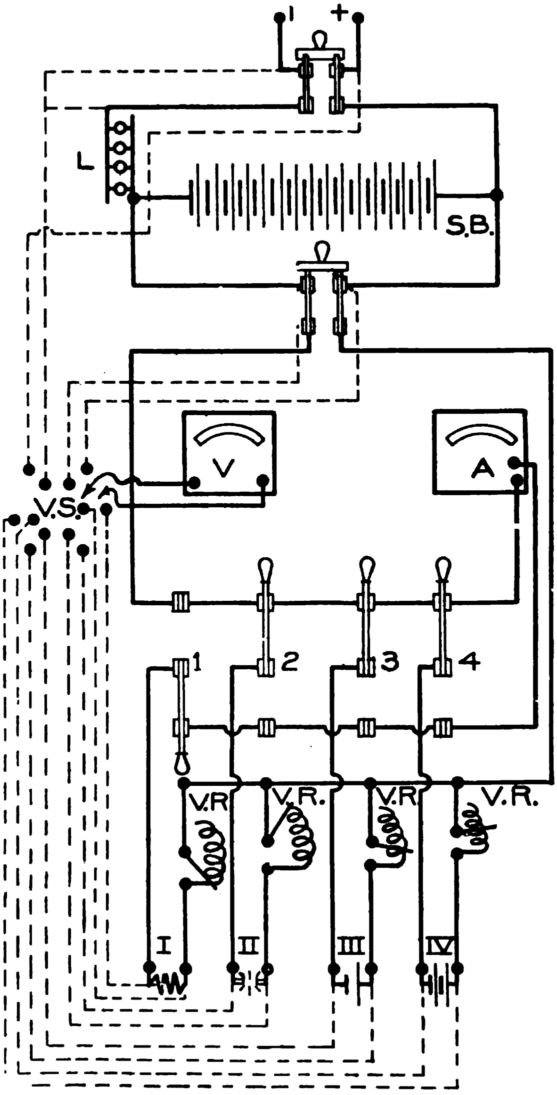


Fig. 25. Diagram of Connections of a Laboratory Equipment Arranged to Supply Current for Four Independent Operations.

When a large current is wanted, as in the case of ammeter calibration, the cells may be connected in parallel and discharged through a low resistance, thus cutting down the energy required for the test. A storage battery may also be used to step up the voltage, the cells being connected in parallel groups for charging, and in series for discharging.

The special arrangement shown in Fig. 25 consists of a storage battery *S.B.*, the charging current for which is regulated by a bank of incandescent lamps *L.* Where a large-capacity battery is employed, a rheostat or motor-dynamo can be substituted for the lamps. In the instance shown, four distinct operations may be carried on simultaneously, without having one interfere with the other. Each one of the circuits is supplied with a regulating device *V. R.*, so that any desired current density is obtainable at the electrodes of the experimental devices I, II, III, and IV. The arrangement of the voltmeter circuits is such that the voltage of each individual circuit can be readily obtained through the use of the twelve-point voltmeter switch at *V. S.* The switching arrangement is such that by means

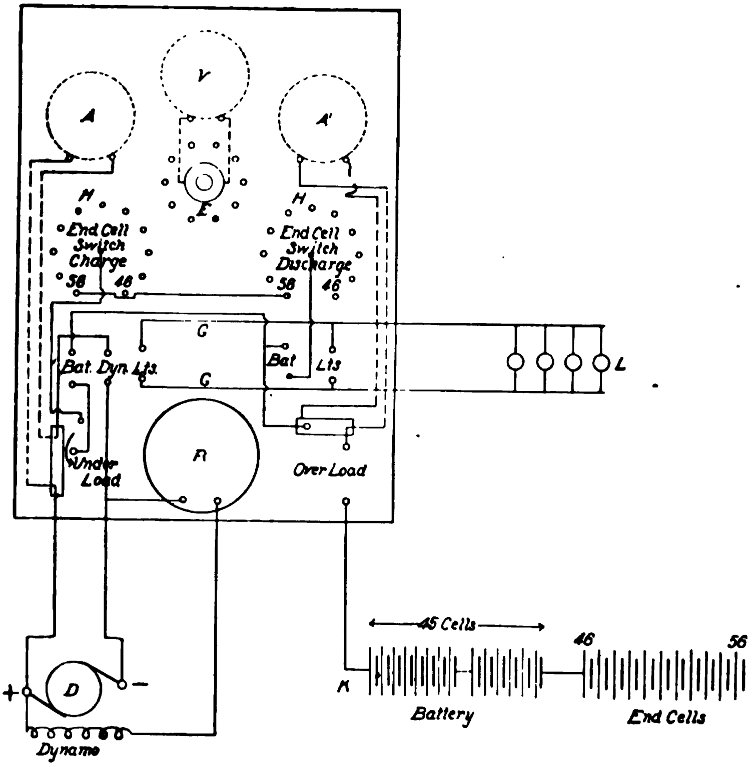


Fig. 26. Switchboard, Dynamo, and Battery Connections.

of one ammeter *A*, separate readings of the current in each branch circuit may be made, or the total current read. For example, with the switches as shown in the figure, the current flowing through the first apparatus consisting of a resistance furnace is being measured. If switch 1 were thrown in the opposite direction, and switch 2 had its position reversed, the current of group II would be shown by the ammeter. If all the switches were placed in the same position as switch 1, the ammeter would indicate the total current drawn by the four pieces of experimental apparatus.

Connection and Regulation of Storage Batteries. The complete control of a battery in an electric-lighting plant requires provision to be made for feeding the lamps, etc., from either the dynamo or battery separately, or from the two working in parallel; and it should be possible to charge the battery at the same time that lamps are being supplied. To accomplish these results requires three switches—one to connect the battery to the dynamo, one to connect the lamps to the dynamo, and one to connect the lamps to the battery. In some plants the second switch is omitted, because the lamps are always fed by the battery alone, the latter being charged during the day, when no lamps are in use. However, it would seem desirable to have all three switches in every plant in order to be able at least

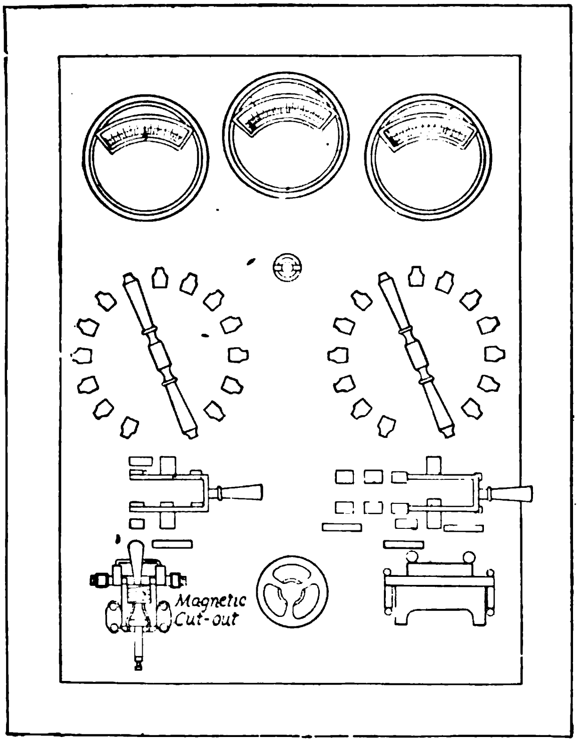


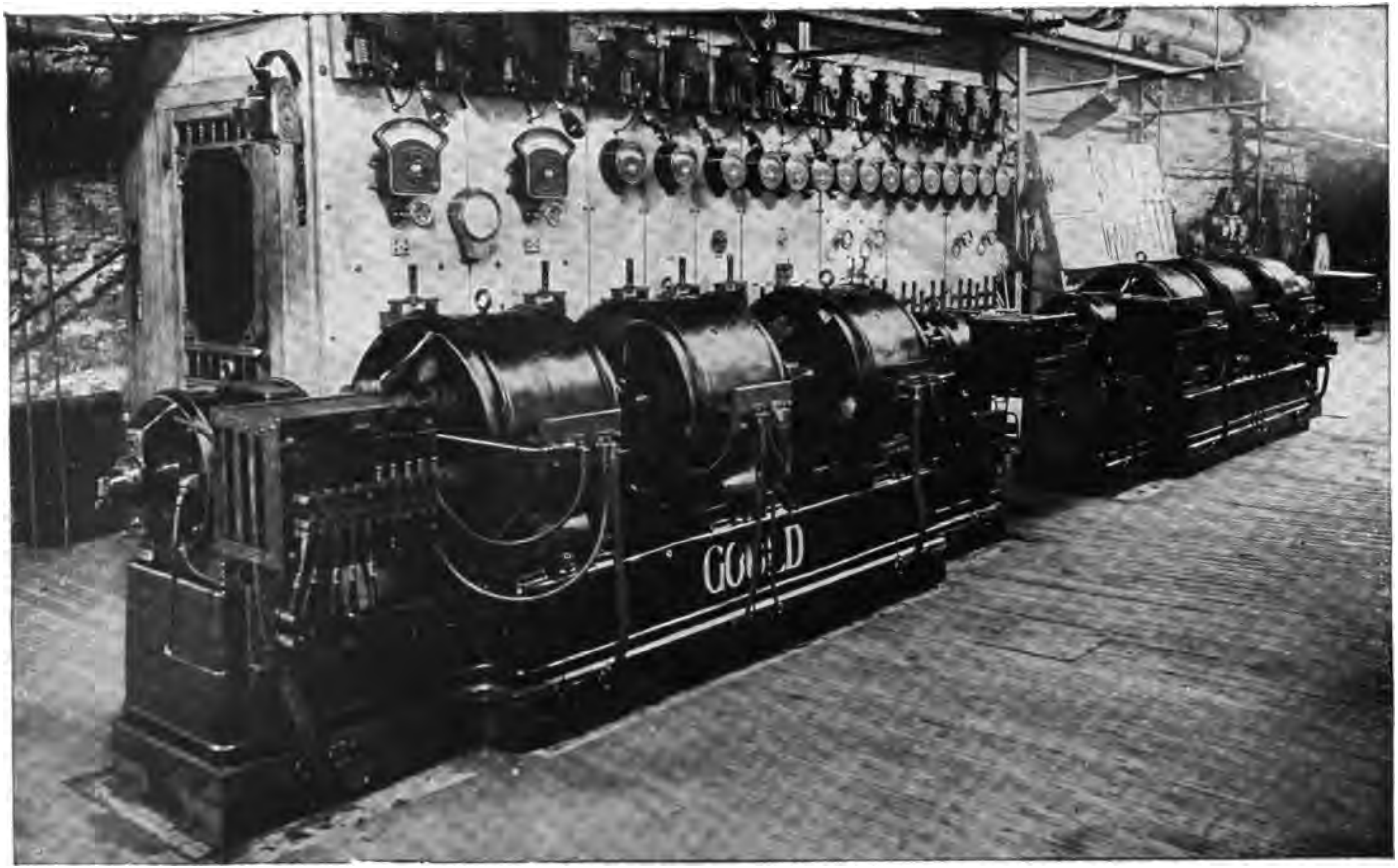
Fig. 27. Face of Switchboard.

to supply lamps and charge the battery at any time. In the battery circuit, there should be an ampere-meter having a scale on both sides of zero, so that it shows whether the battery is being charged or discharged, as well as the value of the current. Another similar ampere-meter is required in the circuit between the dynamo and the battery, to show the direction and amount of current. A third ampere-meter is desirable in the lamp circuit, to show the total current supplied to the lamps; but it need indicate only on one side of zero, since the current there always flows in the same direction. A voltmeter is required with a three-way switch, which enables it to be connected to the dynamo, battery, or lamps respectively.

An automatic overload switch must be inserted in the battery circuit so as to open or introduce resistance into the circuit when the current becomes excessive. An automatic cut-out is required between the dynamo and the battery to open the circuit when the charging current falls below a certain value, and thus avoid any danger of the battery discharging through the dynamo, if from any cause the E. M. F. of the latter drops below that of the former. This completes the ordinary measuring and circuit-controlling apparatus employed in connection with storage batteries. The arrangement is shown diagrammatically in Fig. 26, in which A and A^1 are the two ampere-meters, the third one being omitted in this case; V is the voltmeter; E the voltmeter switch to connect to the dynamo, battery, or lamps as desired; G the bus-bars; L, lamps; D, dynamo; R, rheostat in field-circuit of dynamo.

The regulating device consists of eleven end-cells, which are connected to corresponding contacts on the end-cell switches (Fig. 26). But as the drawing of these connections would complicate the figure, they have been omitted. Fig. 27 shows the switchboard with these devices mounted upon it.

Parallel Charge, Series Discharge. With batteries of small capacity, where it is not advisable or convenient to raise the generator voltage in order to charge all the cells in a single series, it is usual to divide the battery into two parts and charge each half of the battery individually, through a resistance from the main lines. This method is inefficient, however, and should be employed only with small equipments. Fig. 28 shows a diagram of connection for charging in this manner, and coupling the two halves of the battery in series



SWITCHBOARD AND BOOSTERS
Gould Storage Battery Co.

during discharge, the discharge voltage being also regulated by resistance, there being no end cells employed.

Regulation of Storage Batteries. This is one of the most troublesome problems involved in the practical use of storage batteries. It arises from the fact that the voltage falls continually from the beginning to the end of discharge. To be sure, this decline is gradual; but its total value is large, being from about 2.2 to about 1.8 volts, which is a decrease of nearly 18 per cent.

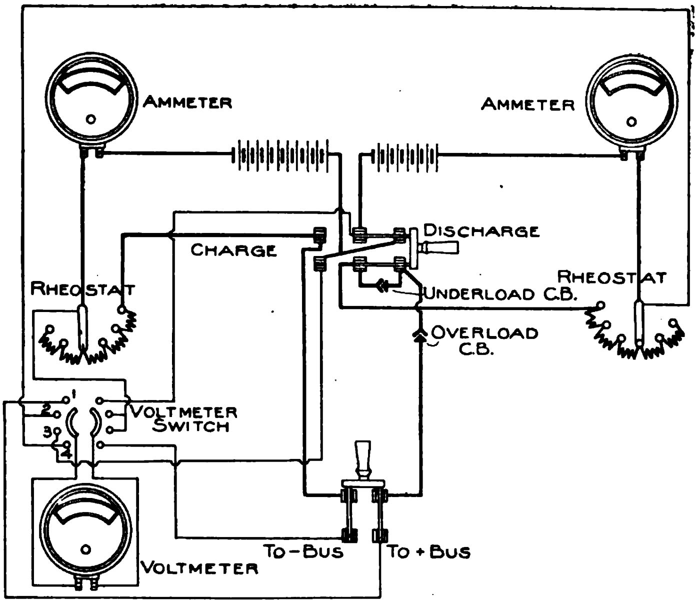


Fig. 28. Connections for Parallel Charge, Series Discharge.

In order to maintain a constant voltage, the usual plan is to have a number of extra cells, which are successively switched into circuit as the potential falls. These reserve cells and the switches which control them are represented in Fig. 26.

The contact-pieces of these switches must be made in such a way that they do not short-circuit the cells as they pass from one point to the next. This is accomplished by splitting the movable contact arm into two parts, between which a certain amount of resistance is introduced, so that when the two parts happen to rest on two adjacent contact-points, the resistance prevents the cell which is connected to these two points from being short-circuited, and also avoids breaking the circuit.

The number of extra cells depends upon conditions; for 110-volt lamps, it would require 51 cells to obtain 112.2 volts when fully charged and giving 2.2 volts each, assuming the drop on the conductors at 2 per cent. When the battery becomes discharged, and its potential falls to 1.8 volts per element, 10 additional cells, or 61 in all, would be needed. These would yield 111.8 volts, assuming the average potential of the reserve cells to be 2 volts, since they have not been discharged to the same extent as the original battery. If the drop on the conductors is 10 per cent of the lamp voltage, the potential at the battery will have to be 110 + 11 = 121. This will necessitate 4 more elements, or a total of 65, when the 51 original cells are fully discharged to 1.8 volts, and the 14 extra cells give 2 volts each.

For a three-wire system, the above figures should, of course, be doubled. This switching of extra cells into and out of the circuit obviously results in discharging them unequally; hence they require to be charged to a corresponding extent. This is accomplished by successively cutting the cells out of circuit as soon as they become fully charged, the last cell which was put into the circuit being fully charged in the shortest time, and so on. The amount of charge is determined by the methods already given. If the cells employed are not injured by overcharging, they may be left in circuit until the entire battery is fully charged. This saves the trouble of operating the switch; but it is wasteful of energy, since the full counter-E. M. F. and resistance of the charged cells must be overcome, which requires about 2.5 volts more per element. The switches might be operated automatically by a voltage regulator or by clockwork.

REGULATION OF GENERATOR IN CHARGING STORAGE BATTERIES

The variation in E. M. F. which occurs in accumulators renders it somewhat difficult to regulate the generators employed to charge them. A constant potential will give a decreasing rate of charge, owing to the gradual rise in counter-E. M. F. This is advantageous in that it enables the cells to receive a larger charge; but the increase in their voltage is so great that it is practically necessary to regulate the charging potential. In practice it is customary to maintain the charging current approximately constant for considerable periods of time; otherwise it would be difficult to determine the quantity of energy put into the battery, and its efficiency. When extra cells are used, they facilitate the regulation of the generator, since they are gradually cut out as the E. M. F. rises.

If the lamps are supplied at the same time that the battery is being charged, some provision must be made for the fact that it may be necessary for the voltage of the dynamo to be considerably higher than that required by the lamps. One plan is to have two separate switches connected to the reserve cells, as shown in Fig. 26, the charging current from the dynamo being led in through one, and the current for the lamps passing out through the other, so that the potential can be independently controlled in the two circuits. Another method is to insert counter-E. M. F. cells (without active material) in the circuit between the dynamo and the lamps, in order to bring down the voltage of the former to suit the latter. The number of these cells is varied in accordance with the excess of the potential of the dynamo.

Simple resistance coils may be used in place of the counter-E. M. F. cells to reduce the pressure; but the cells have the great advantage, that they have an effect practically independent of variations in the current. All these methods, however, involve a waste of power, the value of which in watts is the product of the current in amperes and the number of volts by which the potential is cut down. In small plants this loss is not serious, but in large plants or central stations it may become very considerable.

Booster Methods of Regulation. The best plan is to make use of a *booster*, in which case the main dynamos are run at the proper voltage to supply the lamps directly, and the additional pressure required to charge the battery is furnished by the booster. This is connected in series with the dynamo, being inserted in the circuit between the latter and the battery.

When a battery is placed at the end of a long feeder to compensate for line drop, and at light loads to act as a storage reservoir, it is not usual to equip this *floating battery* with any regulating device. In such cases the battery is simply connected across the line, and the charge and discharge are determined by the feeder drop. For instance, when a small load is on the line, the drop is small, and the potential applied across the battery terminals is high enough to send a charging current into the battery; if the load on the line increases, the drop naturally increases, the pressure at the end of the line falls, and, if it falls below the battery voltage, the battery discharges in parallel with the generator, carrying a certain portion of the load. The floating battery has the advantage of simplicity, and acts immediately, as it has no time lag, which is always present in any apparatus depending upon changes in magnetization. Usually the variations in voltage and the fluctuations in load are too great for successful operation of a floating battery on any but an electric railway or power circuit, and a booster is required if incandescent lighting is a part of the load.

The duty of a booster is to vary the voltage at the battery terminals with variation in load, causing charging or discharging of current as conditions may require. The booster is an auxiliary dynamo, the E. M. F. of which is used to raise or lower the voltage in the battery circuit. These machines are classified as *series, shunt, compound, differential,* and *constant-current* boosters.

Shunt Booster. This is a shunt dynamo, driven by any source of power, having its armature circuit in series with the line from generator to battery. This form is used in plants where the battery is not designed to take up load fluctuations, but is in service only to carry the peak of the load, being charged during periods of light load, and discharged in parallel with the generator. It acts to increase the voltage applied to the battery so that the charg-

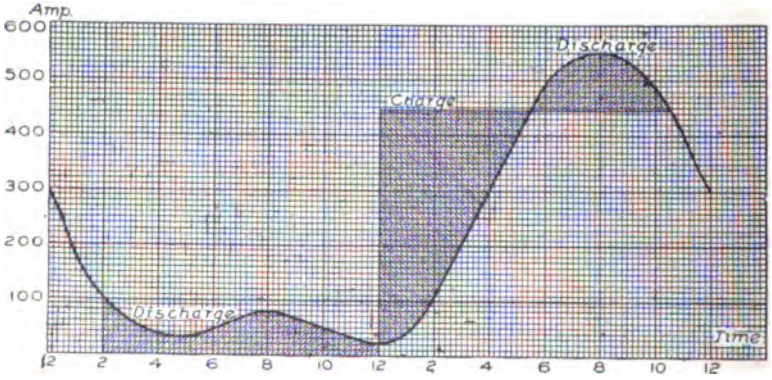


Fig. 29. Load Diagram of Case in which a Shunt Booster is Applicable.

ing current will flow into the latter. As a rule, the battery used in conjunction with a shunt booster is made large enough to carry the entire load during the light-load period. As the battery discharges and its voltage drops, the end-cells (regulation cells) are cut in and the proper voltage maintained. Fig. 29 shows a load diagram to which this system is applicable, and Fig. 30 shows diagrammatically the connections of this system. The booster (7) is direct-connected to and driven by a shunt-covered motor (8), which takes current from the main bus-bars. The field of the booster is provided with a single winding excited from the generator circuit. This winding has a rheostat (10) in series with it so as to be able to regulate to booster E. M. F. It is to be noted that the shunt booster is not applicable where there are sudden fluctuations which are great compared with the capacity of the generator, and that it is not automatic in changing from charge to discharge, the switching being performed by hand.

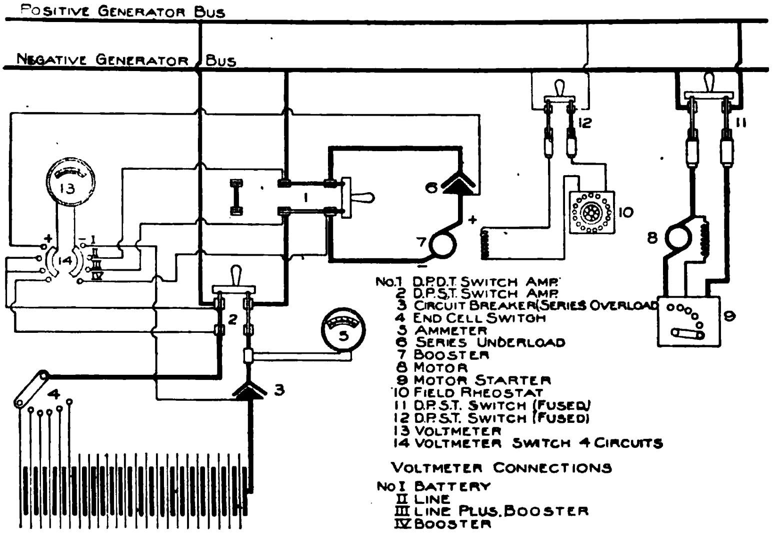


Fig. 30. Shunt Booster Connections.

Series Booster. The connections are like those of the shunt booster with the battery and booster in series across the line; but the field of booster being in series with the battery circuit, its E. M. F. is zero when no current is flowing in or out of the battery. Should the voltage of the line rise, due to a decrease of load, and a charging current flow into the battery, the E. M. F. of the booster would increase, and thus tend to increase the rate of charge. The reverse occurs when the battery discharges, as an increase of load on the line increases the current through the series field of the booster, thus raising the voltage of discharge so that the battery carries a larger part of the load.

This booster acts to compound the battery on discharge, and tends to maintain a constant voltage on the line. It depends on the fact that the generator voltage falls when the load increases; hence it is used with a shunt generator or equivalent source of supply.

This system is applicable to power, but not to lighting purposes, and is similar in its operation to a floating battery. It is not so extensively used as the compound and differential booster arrangements, which give better regulation under similar conditions.

Compound Booster. This system is used on railway and power circuits with great fluctuations in load, the battery action to prevent excessive drop and to assist the generating machinery in carrying the load, relieving it from the strain of sudden rushes of current. The connections of this system are indicated in Fig. 31, and the operation is as follows: Under normal load conditions the shunt field F_h of the booster creates an E. M. F. in the same direction as the battery, tending to discharge it. Calling E_g the generator E. M. F.; E_a the booster E. M. F.; and E_b the battery E. M. F., we have $E_g - E_a = E_b$ when no current is flowing into or out of the battery. In this case the generator carries the whole external load.

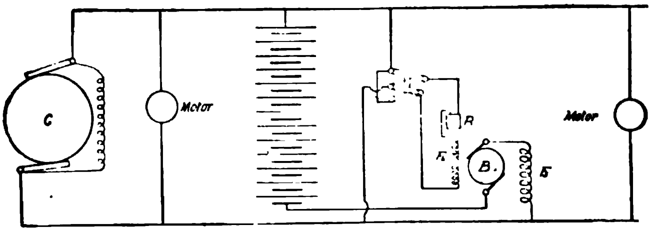


Fig. 31. Compound Booster Connections.

If the load increases, E_g decreases, so that $E_b - E_a$ is greater than E_g, and the battery begins to discharge. In discharging, the current passes through the series field F_s of the booster and produces a proportional E. M. F., acting with the shunt field to raise E_a, thus increasing the battery discharge and shifting more of the load from the generator, until the system becomes balanced.

If the load on the external circuit be light, the generator voltage E_g rises and current flows into the battery. In this case the series field acts against the shunt field and decreases E_a, so that the generator voltage is greater than booster and battery voltage combined, thus increasing the rate of charge of the battery, until the load causes the generator voltage to drop to normal and the system is again balanced. The battery and booster can be placed at the power house or at the point at which the greatest drop is likely to occur.

A battery can also be used to help out the generators at the peak of the load, by increasing the shunt-field current and thus causing E_a-E_b to be greater than E_g.

Since this system also depends for its action upon the drop of voltage with increase of load, it is only applicable to shunt-wound generators or equivalent source.

Differential Boosters. The differential booster system most commonly used is shown in Fig. 32. The compensating field S_1 prevents the variation of the battery E. M. F. from disturbing the equilibrium of the system. If the battery E. M. F. be lower than normal, it will not discharge rapidly enough to relieve the generator from overload fluctuations, unless the booster E. M. F. be increased; and the generator will therefore have to supply a current of greater than its normal value. If, however, a current of greater value than the normal flows through S_1, the value of f-S_1 is decreased, and S_2 still further overpowers the resultant of f-S_1 and causes a higher booster E. M. F., tending to discharge the battery, thus bringing down the generator load to normal. Should the battery E. M. F. be above its normal value, the battery would discharge too rapidly and carry

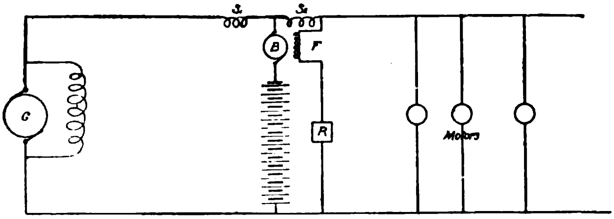


Fig. 32. Differential Booster Connections.

more than its share of the load; in this case $f-S_1$ is greater than it should be, and the booster E. M. F. causes the load to become evenly distributed between the battery and generator.

In operating this system, the varying load must be beyond the booster equipment. If desired, the coils S_1 and S_2 may be short-circuited so that the battery may be charged more rapidly.

Constant-Current Booster. In systems having short lines and small drop, it is often desirable to have the voltage fall on sudden application of an overload, so that the rush of excessive current is prevented. This rush of current occurs in buildings where elevator and power motors constitute a large percentage of the load; and to prevent it, the *constant-current booster* system is used.

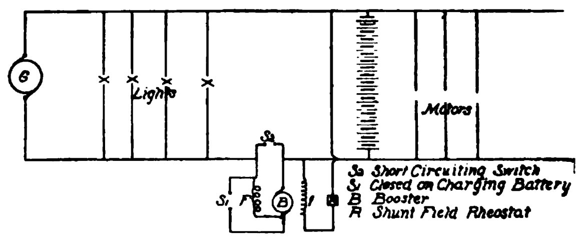


Fig. 33. Constant-Current Booster Connections.

Fig. 33 represents a constant-current booster system, in which the main current passes through the armature and series field of the booster; and this current does not reverse.

The voltage impressed on a fluctuating load of motors, on the right, is greater than that impressed on a non-fluctuating load of lamps on the left, by the amount of the booster voltage.

The shunt-coil f creates an E. M. F. in the same direction as that of the generator; while the series-coil F opposes it.

Should a load come in the motor portion of the circuit, the generator sends a greater current through the series coil S, the action of which reduces the booster E. M. F. in direct proportion to this rush of current, and causes the booster E. M. F. to vary inversely as the motor load, thus tending to maintain an almost constant current delivery from generator. If it is desired to have the battery furnish power to both lights and motors, at periods of light load, and not to use the generator, this can be done by simply opening the generator switch and short-circuiting the booster by closing switch S_2.

The switch S_1 is closed in charging the battery, as the rate of charge can be controlled by varying the shunt-field resistance R.

This is often done, when the battery has been carrying a heavy load for some time and the recharging must be hurried.

In the automatic booster systems already described, the regulation is obtained by two or more field windings acting differentially or cumulatively.

Systems of External Control. In the following systems of booster control, only a single field winding is provided, and this winding is excited from the main bus-bars through an automatic field regulator which varies the field current to produce the necessary booster E. M. F. as the load on the line changes. The booster armature is connected in series with the battery and generator as heretofore. Figs. 34 and 35 show diagrammatically the connections of the differential and constant-current systems arranged on this plan.

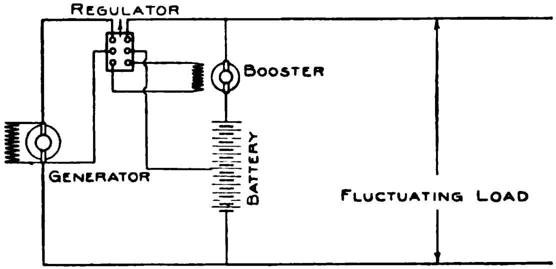


Fig. 34. External Control Differential Booster System.

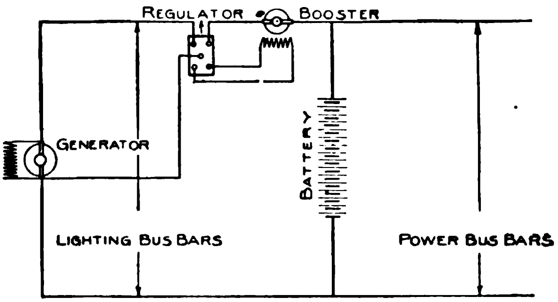
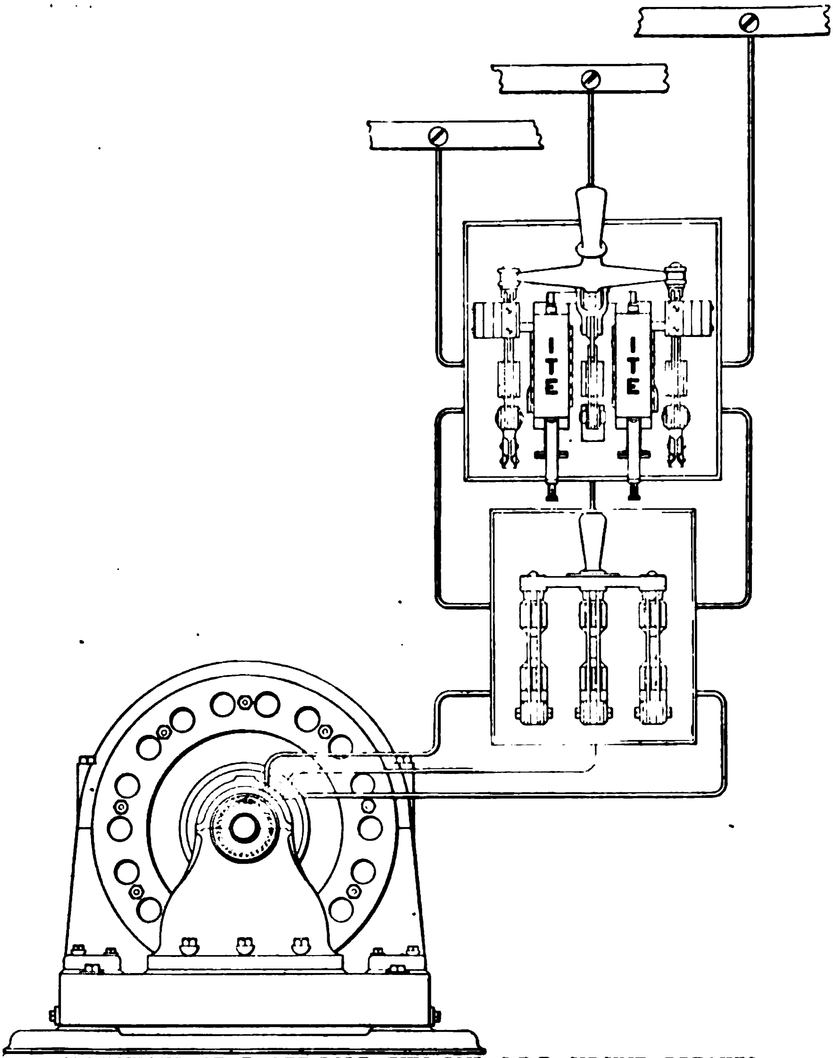


Fig. 35. External Control Constant-Current System.

These externally controlled booster equipments are the system employed by the General Storage Battery Company, and in one of these constant-current systems the following excellent regulation was obtained: The load across the power bus-bars was a rapidly fluctuating one, varying instantly from zero to 2,500 amperes, while the average current required amounted to only 150 amperes. With no load across the power bus-bars, the booster passed 150 amperes from the generator to the battery, tending to charge the latter; with a sudden increase of power demands from zero to 2,500 amperes, the generator current rose to a value of only 159 amperes. This example brings out the definition of a constant-current booster—that is, it should be one which maintains a practically constant power load on the generator.



CONNECTIONS OF THREE-POLE TWO-COIL I-T-E CIRCUIT BREAKER.

For the Protection of Three-Phase Alternating Current Motor.

The Cutter Company.

POWER TRANSMISSION.

ELECTRICAL.

The subject of power transmission is a very broad one; dealing with the transmission and distribution of electrical energy, as generated by the dynamo or alternating-current generator, to the receivers. The receivers may be lamps, motors, electrolytic cells, etc. Electric distribution of power is better than other systems on account of its superior flexibility, efficiency, and effectiveness; and we find it taking the place of other methods in all but a very few applications. For some purposes the problem is comparatively simple, while for other uses, such as supplying a large system of incandescent lamps, scattered over a comparatively large area, it is quite complicated. As with other branches of electrical engineering, it is only in recent years that any great advances have been made in the means employed for transmission of electrical power, and while this advance has been very rapid, there is still a large field for development.

In a study of this subject the different methods employed and their application, the most efficient systems to be installed for given service, the preparation of conductors and the calculation of their size, together with the proper installation of the same, should be considered.

CONDUCTORS.

Material Used. Power, in any appreciable amount, is transmitted, electrically, by the aid of metal wires, cables, tubes, or bars. The materials used are iron or steel, copper and aluminum. Other metals may serve to conduct electricity but they are not applied to the general transmission of energy. Of these three, the two latter are the most important, iron or steel being used to a considerable extent only in the construction of telephone and telegraph lines, and even here they are rapidly giving way to copper. Steel may be used in some special cases, such as extremely long spans in overhead construction or for the working conductors for railway installations using a third rail. Phosphor bronze has a limited use on account of its mechanical strength.

Copper and aluminum are used in the commercially pure state and are selected on account of their conductivity and comparatively low cost. The use of aluminum is at present limited to long-distance transmission lines or to large bus-bars, and is selected on account of its being much lighter than copper. It is not used for insulated conductors because of its comparatively large cross-section and consequent increase in amount of insulation necessary.

TABLE I.

Copper Wire Table.

A. W. G. or B. & S.	Dimensions.		Resistance.		
	Diameter.	Area.	Ohms per foot.		
	Inches.	Circular Mils.	At 20° C.	At 50° C.	At 80° C.
0000	.460	211,600	.00004893	.00005467	.00006058
000	.4096	167,800	.00006170	.00006893	.00007640
00	.3648	133,100	.00007780	.00008692	.00009633
0	.3249	105,500	.00009811	.0001096	.0001215
1	.2893	83,690	.0001237	.0001382	.0001532
2	.2576	66,370	.0001560	.0001743	.0001932
3	.2294	52,630	.0001967	.0002198	.0002435
4	.2043	41,740	.0002480	.0002771	.0003071
5	.1819	33,100	.0003128	.0003495	.0003873
6	.1620	26,250	.0003944	.0004406	.0004883
7	.1443	20,820	.0004973	.0005556	.0006158
8	.1285	16,510	.0006271	.0007007	.0007765
9	.1144	13,090	.0007908	.0008835	.0009791
10	.1019	10,380	.0009972	.001114	.001235
11	.09074	8,234	.001257	.001405	.001557
12	.08081	6,530	.001586	.001771	.001963
13	.07196	5,178	.001999	.002234	.002476
14	.06408	4,107	.002521	.002817	.003122
15	.05707	3,257	.003179	.003552	.003936
16	.05082	2,583	.004009	.004479	.004964
17	.04526	2,048	.005055	.005648	.006259
18	.04030	1,624	.006374	.007122	.007892

Resistance. The resistance of electrical conductors is expressed by the formula:

$$R = \frac{L}{A} f$$

where R = total resistance of the conductors considered.
L = length of the conductors in the units chosen.
A = area of the conductors in the units chosen.
f = a constant depending on the material used and on the units selected.

For cylindrical conductors, L is usually expressed in feet and A in circular mils. By a circular mil is meant the area of a circle .001 inches in diameter. A square mil is the area of a square whose sides measure .001 inches and is equivalent to 1.27 circular mils. Cylindrical conductors are designated by gauge number or by their diameter. The Brown & Sharpe (B. & S.) or American wire gauge is used almost universally and the diameters corresponding to the different gauge numbers are given in Table I. Wires above No. 0000. are designated by their diameter or by their area in circular mils.

TABLE II.

Resistances of Pure Aluminum Wire.

A. W. G. or B. & S.	Resistance at 75° F.	
	R Ohms 1,000 ft.	Ohms per mile.
0000	.08177	.43172
000	.10310	.54440
00	.13001	.68645
0	.16385	.86515
1	.20672	1.09150
2	.26077	1.37637
3	.32872	1.7357
4	.41448	2.1885
5	.52268	2.7597
6	.65910	3.4802
7	.83110	4.3885
8	1.06802	5.5355
9	1.32135	6.9767
10	1.66667	8.8000
11	2.1012	11.0947
12	2.6497	13.9900
13	3.3412	17.642
14	4.3180	22.800
15	5.1917	27.462
16	6.6985	35.368
17	8.4472	44.602
18	10.6518	56.242

A convenient way of determining the size of a conductor from its gauge number is to remember that a number 10 wire has a diameter of nearly one-tenth of an inch and the cross-section is doubled for every three sizes larger (Nos. 7, 4, etc.) and one-half as great for every three sizes smaller (Nos. 13, 16, etc.). 1,000 feet of number 10 copper wire has a resistance of 1 ohm and weighs 31.4 pounds.

When f is expressed in terms of the mil foot, a wire one foot in length having a cross-section of one mil, its value for copper of a purity known as **Matthiessen's Standard,** or copper of 100% conductivity, is 9.586 at 0° C.* For aluminum its value is given as 15.2 for aluminum 99.5% pure. Table II gives the resistance of aluminum wire.

This shows the conductivity of aluminum to be about 63% of that of copper. The conductivity of iron wire is about $\frac{1}{7}$ that of copper.

Matthiessen's standard is based on the resistance of copper supposed, by Matthiessen, to be pure. Since his experiments, improvements in the refining of copper have made it possible to produce copper of a conductivity exceeding 100%. Copper of a conductivity lower than 98% is seldom used for power transmission purposes.

Temperature Coefficient. The specific resistance (resistance per mil foot) is given for copper as 9.586 at 0° Centigrade. Its resistance increases with the temperature according to the approximate formula:

$$R_t = R_o(1 + at)$$

where R_t = Resistance at temperature $t°$, Centigrade.

R_o = " " 0° C.

a = .0042, commercial value.

The value of a for aluminum does not differ greatly from this. It is given by Kempe as .0039.

Weight. The specific gravity of copper is 8.89. The value for aluminum is 2.7, showing aluminum to weigh .607 times as much as copper for the same conductivity or resistance. It is this property which makes its use desirable in special cases. Iron, as used for conductors, has a specific gravity of 7.8.

Mechanical Strength. Soft-drawn copper has a tensile strength of 25,000 to 35,000 lbs. per sq. in. Hard-drawn copper has a tensile strength of 50,000 to 70,000 lbs. per sq. in., depending on the size; the lower value corresponding to Nos. 0000 and 000.

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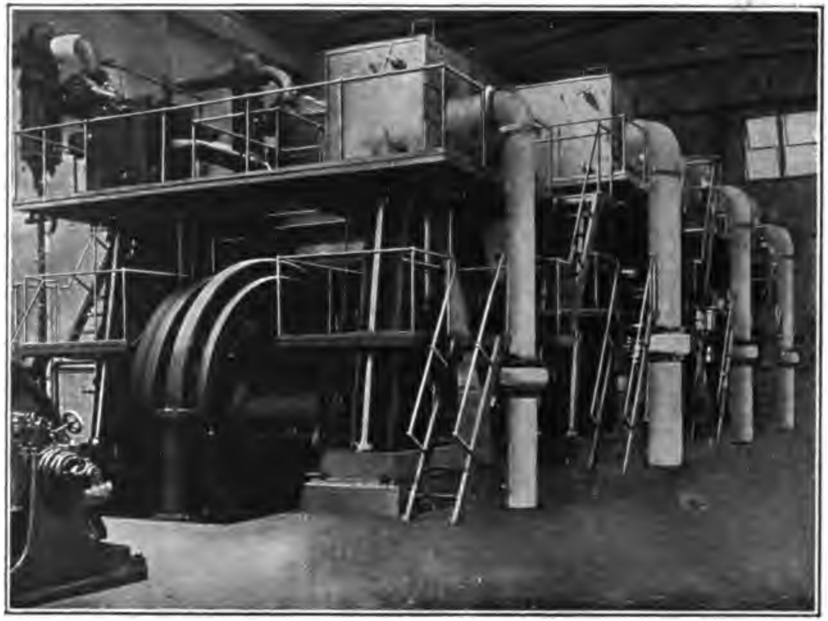
*The commercial values given for the mil foot vary from 10.7 to 11 ohms.



ONE 400 K. W. AND THREE 750 K. W. ENGINE TYPE A. C. GENERATORS, TWO-PHASE, 440 VOLTS, 60 CYCLES

Westinghouse Electric & Manufacturing Co.

Aluminum has a tensile strength of about 33,000 lbs. per sq. in. for hard-drawn wire $\frac{1}{4}$ inch in diameter.

Effects of Resistance. The effect of resistance in conductors is three-fold.

1. There is a drop in voltage, determined from Ohm's law,

$$I = \frac{E}{R} \text{ or } E = IR.$$

2. There is a loss of energy proportional to the resistance and the square of the current flowing. Loss in watts $= I^2R = \frac{E^2}{R}$

3. There is a heating of the conductors, due to the energy lost, and the amount of heating allowable depends on the material surrounding the conductors. The drop in voltage or the heating limit is usually more important in the design of a transmission system than the loss of energy.

Capacity of Conductors for Carrying Current. The temperature of a conductor will rise until heat is lost at a rate equal to the rate it is generated so that a conductor is only capable of carrying a certain current with a given allowable temperature rise. The limit of this rise in temperature is determined by fire risk, or injury to insulation. A general rule is that the current density should not exceed 1,000 amperes per square inch of cross-section for copper conductors. This value is too low for small wire and too high for heavy conductors, and it is governed by the way in which the conductors are installed. This value serves for bus-bars where the thickness of the copper used is limited to $\frac{1}{4}$-inch. Curves shown in Fig. 1 are applicable to switchboard wiring, and Table VII of "Electric Wiring" gives safe carrying capacity of conductors for inside wiring. Perrine gives the following table showing the class of conductors to be used under various conditions:

TABLE III.

Conductors for Various Conditions.

PART I.

Reference No.	Remarks.	Reference No.	Remarks.
1.	Not allowed.	8.	In insulating tubes.
2.	Clear spaces.	9.	In wood moldings.
3.	Through trees.	10.	Without further precaution.
4.	On glass insulators.	11.	If necessary.
5.	On porcelain knobs.	12.	Below 350 volts.
6.	In porcelain cleats.	13.	Above 350 volts.
7.	In wood cleats.		

TABLE III.

Class of Conductors for Various Positions.

PART II.

Description of Conductor.	Position.							
	Open air.	Dry rooms.	Damp rooms.	Concealed under floor or wall.	Rooms containing gases or vapor.	Under water.	Underground.	
							Buried.	In conduit.
Bare wire	2-4 3-1	1	1	1	1	1	1	2-4
Underwriter's insulation	1	2-5 or 6 13-1	1	1	1	1	1	1
Double weatherproof	12-4 13 & 2-4	2-5 or 6 13-1	12-4 13-1	1	1	1	1	1
Triple weatherproof	13-4	13-5 or 6 or 8	12-4 13-1	12-8 13-1	12-4 13-1	1	1	1
Plain rubber	13-4 3-1	13-5	12-5 13-4	13-8	12-5 13-4	11	1	2-5
Taped or braided rubber	13-4	13-5	12-5 13-4	13-8	12-5 13-4	11	1	2-5
Taped or braided cored rubber	13-4	13-5 or 9	12-5 13-4	13-8	12-5 13-4	11	1	2-5
Gutta percha, armored	1	1	1	1	1	10	1	1
Rubber, leaded	10	9	1	8	1	11	..	11
Paper, leaded Fiber, leaded	10	9	1	8	1	11	1	11
Any insulation, leaded and asphalted	10	9	6	8	6	11	11	10

Insulation, in the form of a covering, is required for electrical conductors in all cases with the exception of switchboard busbars and connections and wires used on pole lines, and even these are often insulated. It may serve merely to keep the wires from making contact, as is the case with cotton or silk-covered wire. Again, the wire may be covered with a material having a high specific resistance but being weak mechanically, and this combined with a material serving to give the necessary strength to the insulation. For this purpose yarns are used as the mechanical support, and waxes and asphaltum serve for the insulation proper.

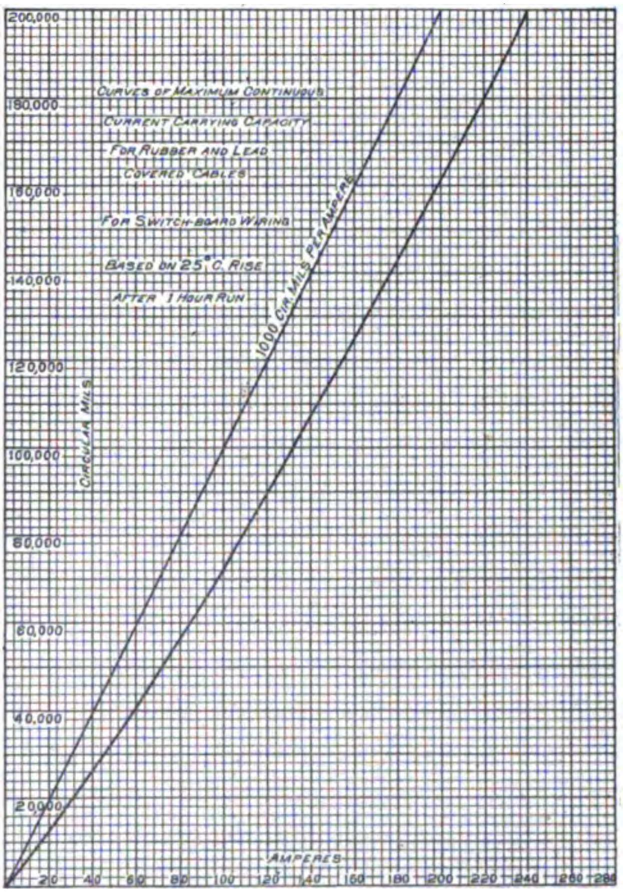


Fig. 1.

Annunciator wire is covered with heavy cotton yarn saturated with paraffine. The so-called **Underwriter's** wire is insulated with cotton braid saturated with white paint. Asphaltum or mineral wax is used for insulating **Weatherproof** wire. It may be applied in several ways, the best insulation being made by covering the conductor with a single braiding laid over asphaltum and then passing the covered wire through the liquid insulation, at the same time applying two cotton braids, and finishing by an external application of asphaltum and polishing. The most complete insulation is made up of a material which gives the most perfect insulation and which is strong enough, mechanically, to withstand pressure and abrasion without additional support.

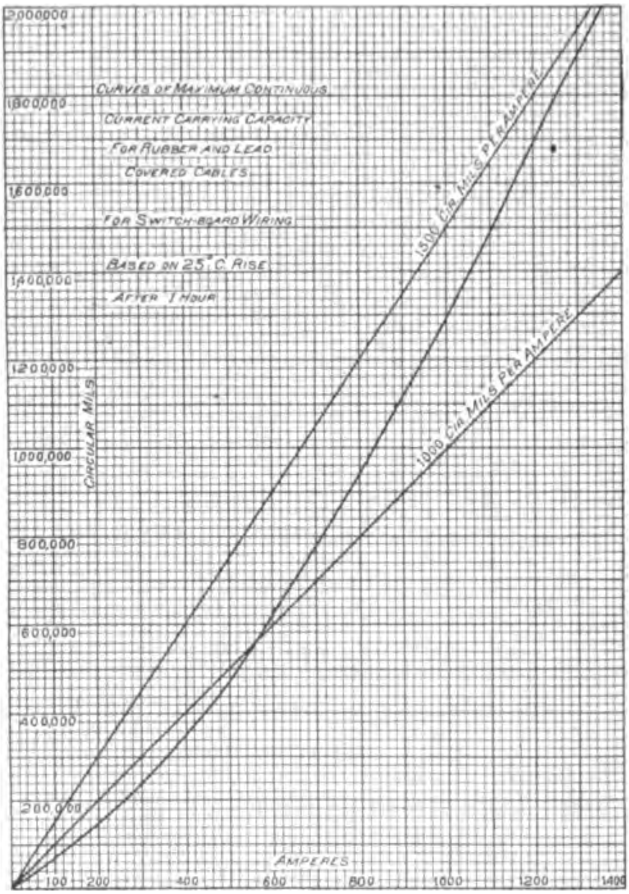


Fig. 1.

Gutta Percha and India Rubber. Gutta percha is used for submarine cables, but rubber is the insulating material most used for electrical conductors. Gutta percha cannot be used when exposed to air, as it deteriorates rapidly under such conditions.

Rubber, when used, is vulcanized, and great care is necessary in the process. This vulcanized rubber is usually covered with braid having a polished asphaltum surface. The insulation of high-tension cables will be considered in the topic, " Underground Construction."

DISTRIBUTION SYSTEMS.

Distribution systems may be divided into *series* systems, *parallel* systems, or combinations, such as *series-parallel* or *parallel-series* systems. Various translating devices may be connected in circuit, changing from one system to the other, and the parallel system may be divided into *single* and *multiple-circuit* systems commonly known as *two*-wire and *three*-, or *five-wire* systems.

Series Systems are applied to series arc lighting, series incandescent lighting, and to constant-current motors driving machinery, or generators feeding secondary circuits. They serve for both alternating and direct currents. Fig. 2 shows the arrangement of units in this system. The current, generated by the dynamo D, passes from the positive brush A (in direct-current systems) through the units L in series to the negative brush B. For lighting purposes, this current has a constant value and special machines are used for its generation. The voltage at the generator depends on the voltage required by the units and the number of units connected in service. As an example, the voltage allowed for a direct-current open-arc lamp and its connections may be taken as 50 volts. If 40 lamps are burning, the potential generated will be 50 × 40 = 2,000 volts. The number of units is sometimes great enough to raise this potential to 6,000 volts; but by a special arrangement of the Brush arc machine, known as the multiple-circuit arc machine, the potential is so distributed that its maximum value on the line is but 2,000 volts, provided the lamps are equally distributed, while the total electromotive force generated is 6,000 volts, when the machine is fully loaded.

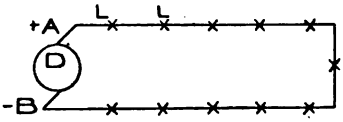


Fig. 2.

The machine is supplied with three commutators and the lamps connected as shown in Fig. 3, which also shows the distribution of potential.

All calculations for series systems are simple. The drop in voltage is obtained from Ohm's law, $I = \frac{E}{R}$. A wire smaller than No. 8 should never be used for line construction, as it would not be strong enough mechanically, even though the drop in voltage with its use should be well within the limit.

The current taken by arc lamps seldom exceeds 10 amperes. For series incandescent lighting, the current may be lower than this, having a value from 2 to 4 amperes. Special devices are used to prevent the breaking of a single filament from putting out all of the lights in the system and automatic short-circuiting devices are used with series arc lamps for accomplishing the same purpose.

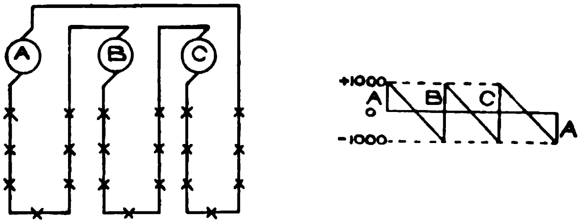


Fig. 3.

As an example of the calculation of series circuits, required the drop in voltage and loss of energy in a line four miles long and composed of No. 8 wire, when the current flowing in the line is 9.6 amperes. From Table 1 we have a resistance of .0007007 ohm per foot for No. 8 wire at 50° C. This gives a resistance of 3.7 ohms per mile, or a resistance of 14.8 ohms for the circuit. The drop in voltage from Ohm's law equals current times resistance or equals $9.6 \times 14.8 = 142$ volts. The loss in energy equals the square of the current times the resistance, equals $9.6^2 \times 14.8 = 1{,}364$ watts. If the circuit contains 80 lamps, each taking 50 volts, the total voltage of the system is 4,142 volts, and the percentage drop in pressure is $\frac{142}{4142} = 3.43\%$.

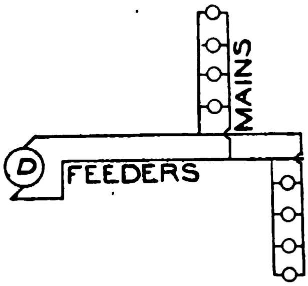


Fig. 4.

Parallel Systems of Distribution. In the parallel or "multiple-arc" system of distribution, the lamps or motors are supplied with a constant potential, and the current supplied by the generators is the sum of the currents taken by each translating device. There are several methods of distribution applicable to this system, each one having some characteristic which makes its use desirable for certain installations. The usual arrangement is to run conductors known as "feeders" out from the station, and connected to these feeders are other conductors known as mains, to which, in turn, the receivers or translating devices are connected. Fig. 4 is a diagram of such a "feeder and main" system.

The feeders may be connected at the same ends of the mains, known as parallel feeding; or they may be connected at the opposite ends of the main, giving us the anti-parallel system of feeding. The mains may be of uniform cross-section throughout, or they may change in size so as to keep the current density approximately constant. The above conditions give rise to four possible combinations; namely:

I. **Cylindrical conductors, parallel feeding. Fig. 5.**
II. **Tapering conductors, parallel feeding. Fig. 6.**
III. **Cylindrical conductors, anti-parallel feeding. Fig. 7.**
IV. **Tapering conductors, anti-parallel feeding. Fig. 8.**

The regulation of the voltage of a system is of particular importance when incandescent lamps are supplied; and the calculation of the drop in voltage to lamps connected to mains supplied with a constant potential should be considered. Without going into detail as to the methods of derivation, we have the following formulæ which apply to the above combinations when the receivers are uniformly distributed and each taking the same amount of current.

Cylindrical conductors, parallel feeding,

$$D = \frac{RIx}{L}(2L - x) \qquad \text{I}$$

Tapering conductors, parallel feeding,

$$D = 2\,RIx. \qquad \text{II}$$

Cylindrical conductors, anti-parallel feeding,

$$D = \frac{RIx}{L}(L - x) \qquad \text{III}$$

Tapering conductors, anti-parallel feeding,

$$D = O. \qquad \text{IV}$$

where D = difference between potentials applied to different lamps.

R = resistance of conductors per unit length at feeding point. This will be a constant quantity for cylindrical conductors, but will change for tapering conductors, having its minimum value at the feeding point, and its maximum value at the end of the main.

I = current in main at feeding point, or point at which the feeders are connected to the mains. In Figs. 5, 6, 7, and 8 the mains only are shown in detail.

x = distance from feeding point to the particular lamps at which the voltage is being considered.

L = length of main.

For Cases I and II the maximum difference of potential is found where $x = L$, that is, at the lamps located at the end of the mains.

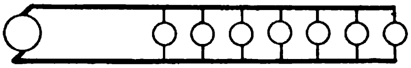


Fig. 5.

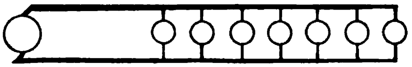


Fig. 6.

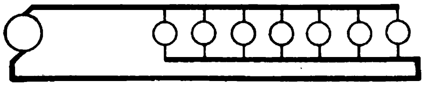


Fig. 7.

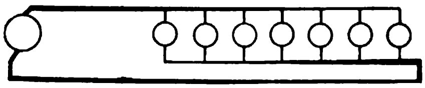


Fig. 8.

For Case III the maximum difference of potential is found where $x = \frac{L}{2}$, or at the lamp located at the middle point of the mains.

For Case IV the potential on all of the lamps is the same, but the difference between the voltage on the feeders and the voltage on the lamps is equal to RI L.

For unequal distribution of receivers and special feeding points the drop in voltage can be calculated by the aid of Ohm's law, but this calculation becomes quite complicated for extensive systems. It usually is sufficient to keep the *maximum* drop within the desired limits when designing electrical conductors for lighting, being careful not to exceed the safe carrying capacity of the wires.

The drop in voltage on the feeders may be calculated directly from Ohm's law when direct current is used, knowing the current flowing and the dimensions of the conductors used.

Additional formulae are given in "Electric Wiring," which will aid in determining the size of wire to be used for a given installation.

As examples of calculation we have the following:

System consists of 20 lamps, each taking .5 amperes. $L = 80$ feet. $R = .01$ ohm per foot at feeding point. Find the maximum difference of potential on the lamps in each of the first three cases.

$$I = 20 \times .5 = 10 \text{ amperes.}$$

Case I. $$D = \frac{.01 \times 10 \times 80}{80} \times (160 - 80) = 8 \text{ volts.}$$

Case II. $$D = 2 \times .01 \times 10 \times 80 = 16 \text{ volts.}$$

Case III. $$D = \frac{.01 \times 10 \times \frac{80}{2}}{80} \times \left(80 - \frac{80}{2}\right) = 2 \text{ volts.}$$

In Case IV the difference in potential applied to the lamps and the potential of the feeders would be $.01 \times 10 \times 80 = 8$ volts.

Again, with the maximum allowable drop given, the resistance of the wires at the feeding point may be determined. For tapering conductors, the current density is kept approximately constant by using wire of a smaller diameter as the current decreases. Thus supposing, as in the case considered, that the resistance at the feeding point was .01 ohm per foot. At a distance of 40 feet from the feeding point the current would be only $\frac{1}{2}$ of 10 or 5 amperes and the size of the wire would be one-half as great, giving it a resistance at this point of .02 ohm per foot.

Feeding Point. In order to determine the point at which a system of mains should preferably be fed, that is, the point where the feeders are attached to the mains, it is necessary to find the electrical center of gravity of the system. The method employed is similar to that used in determining the best location of a power plant as regards amount of copper required, and consists of separately obtaining the center of gravity of straight sections and then determining the total resultant and point of application of this resultant of the straight sections to locate the best point for feeding. Actual conditions are often such that the system cannot be fed at a point so determined, but it is well to run the feeders as close to this point as is practical, as less copper is then required for a given drop in potential.

Consider, as an example, a system such as is shown in Fig. 9. The number of lamps and location of the same are shown in this figure. The loads, A B C D, may be considered as concentrated at A′, a point 33.8 feet from I and equal to A + B + C + D. This point is obtained as follows:

$$Ax = By. \quad 10\,y = 20\,x. \quad x + y = 400. \qquad x = 133.3 \text{ feet.}$$
$$A + B = 30.$$
$$Cx' = Dy'. \quad 15x' = 20y'. \quad x' + y' = 500. \qquad x' = 285.7 \text{ feet.}$$
$$C + D = 35.$$
$$(A + B)\,x'' = (C + D)\,y''. \quad x'' + y'' = 632.4. \qquad x'' = 340.5 \text{ feet}$$
$$30x'' = 35y''.$$
$$A + B + C + D = 65$$

A′ is 6.2 feet from C or 33.8 feet from I.

E and F may be combined to form a group of 30 lamps and the resultant of E, F, G, and H is 70 lamps located at B′, a point 310 feet from J, this point being located in the same manner as A′. Similarly we find the resultant of the loads at A′ and B′ to be 135 lamps located at C′, a point 331.1 feet from I, and the proper feeding point for the system.

A′ = 65 lights, 33.8 feet from I.
B′ = 70 lights, 310 feet from J.
Distance IJ = 360 feet.
Distance from A′ to B′ = 360 + 310 + 33.8 = 703.8 feet.
$65x = 70y.$
$x + y = 703.8$ feet.
$x = 364.9$ feet.
364.9 – 33.8 = 331.1 feet.

The above is a simple definite case. Should the load be variable, the proper feeding point will change with the load, and, in extensive systems, the location of this point can be obtained approximately only. The same method of calculation is employed in locating the points from which sub-feeders are run out from the terminals of the main feeders as is the case in large systems, the voltage being maintained constant at the point where the sub-feeders are connected to the feeders.

Good practice shows the drop in potential to be within the following limits:

From feeding points (points where sub-feeders or mains are attached) to lamps	5	per cent.
Loss in sub-feeders	3	"
Loss in mains	1.5	"
Loss in service wires	0.5	"

The actual **variation** in voltage should not exceed 3%.

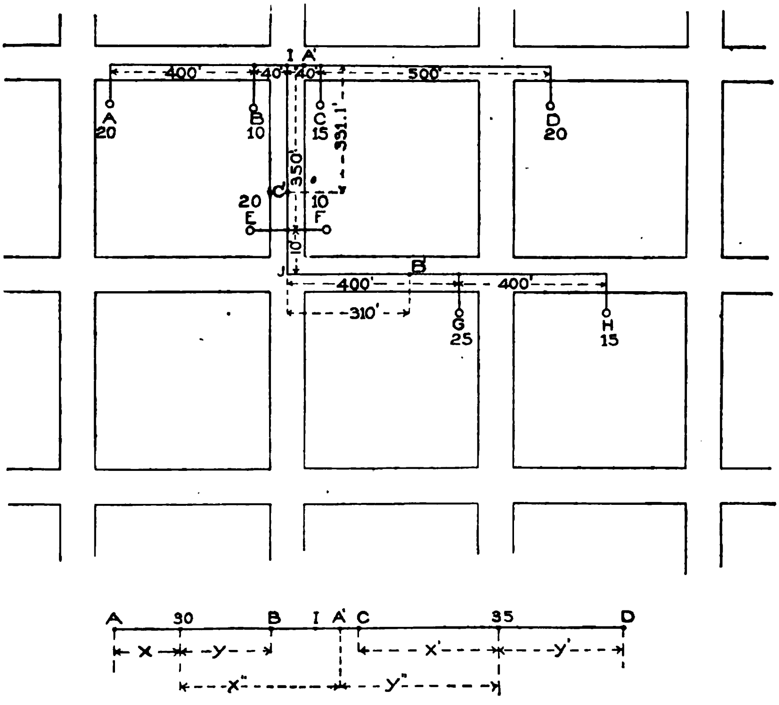


Fig. 9.

In **Series-Multiple and Multiple-Series Systems**, groups of units, connected in multiple, are arranged in series in the circuit, or groups of units are connected in series and those, in turn, connected in multiple, respectively. The application of such systems is limited. They are used to some extent in street-lighting when incandescent lamps are used.

MULTIPLE-WIRE SYSTEMS.

The Three-Wire System. We have seen that in any system of conductors the power lost is equal to I^2R. For a given amount of power transmitted (IE) the current varies inversely with the voltage and consequently the amount of power lost, which is directly proportional to the square of the current, is inversely proportional to the square of the voltage. Hence, for the same loss of power and the same percentage drop in voltage, doubling the voltage of the system would allow the resistance of the conductors to be made four times as great, and wire of one-fourth the cross-section or one-fourth the amount of copper would be required. The voltage for which incandescent lamps, having a reasonable efficiency, can be economically manufactured is limited to 220, while the majority of them are made for 110. In order to increase the voltage on the system, a special connection of such lamps is necessary. The three-wire and five-wire systems are adopted for the purpose of increasing this voltage. Fig. 10 shows a diagram of a three-wire system. Consider the conductor B removed, and we have a series-multiple system with two lamps in series. This arrangement does not give independent control of individual lamps, and the third wire is introduced to take care of any unbalancing of the number of lamps or units connected on either side of the system, and to allow more freedom in the location of the lights. The current flowing in the conductor B, known as the neutral conductor, depends on the difference of the currents required by the units on the two sides of the system. Fig. 11 shows a system in which the loads on the two sides are unequal, an unbalanced system, with the value of the current in the neutral wire at different points. Each unit is here assumed to take one ampere.

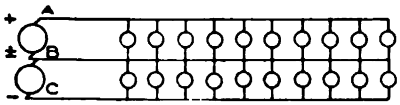


Fig. 10.

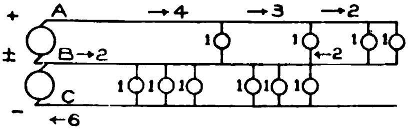


Fig. 11.

As stated above, were no neutral wire required, the amount of copper necessary for a system with the lamps connected, two in series, for the same percentage drop in voltage would be one-fourth the amount necessary for the parallel connection. This may be shown as follows: The current in the wire in the first case is one-half as great, so that the voltage drop would be divided by two for the same size wire. The voltage on the system is twice as great, so that, with the same *percentage* regulation, the actual voltage drop would be doubled. Consequently wire of one-fourth the cross-section and weight may be used. If the neutral wire is made one-half the size of the outside conductor, as is usually the case in feeders, the amount of copper required is $\frac{5}{16}$ of that necessary for the two-wire system. For mains it is customary to make all three conductors the same size, increasing the amount of copper to $\frac{3}{8}$ of that required for a two-wire system. For a five-wire system with all conductors the same size, the weight of copper necessary is .156 times that for a two-wire system.

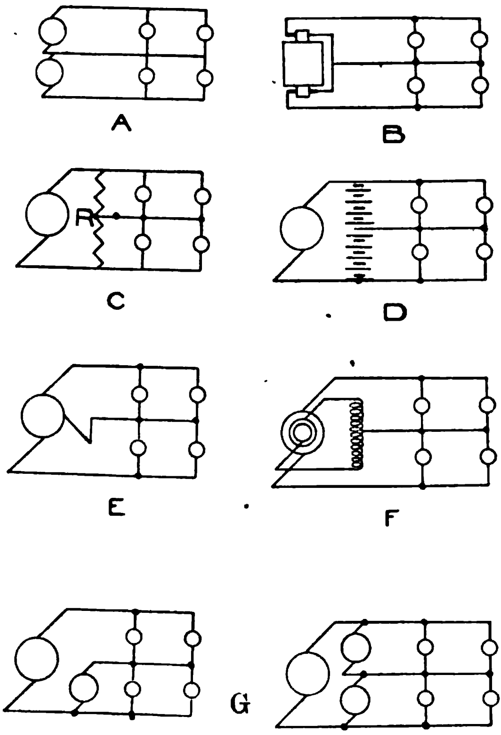


Fig. 12.

Multiple-wire systems have no advantage other than saving of copper, except when used for multiple-voltage systems, while among their disadvantages may be mentioned:

Complication of generating apparatus.
Complication of instruments and wiring.
Liability to variation in voltage, due to unbalancing of load.

Fig. 12 shows some of the methods employed in generating current for a three-wire system.

A. Two dynamos connected in series, the usual method

B. A double dynamo.

C. Bridge arrangement, using a resistance R with the neutral connection arranged so as to change the value of resistance in either side of the system. Has the disadvantage of continuous loss of energy in R.

D. Storage battery connected across the line with neutral connected at middle point.

E. Special dynamo supplied with three brushes.

F. Special machine having collector rings, across which is connected an impedance coil, the neutral wire being connected to the middle point of this coil.

G. Compensators or motor-generator set used in connection with generator. The motor-generator set is known as a balancer set.

Compensators are usually wound for about 10% of the capacity of the machine with which they are used. In the motor-generator set, one side becomes a motor or generator depending on whether the load on that side is less or greater than the load on the opposite side.

Voltage Regulation of Parallel Systems. It is customary to keep the voltage on the mains constant, or as nearly so as possible, at the point where the feeders are attached. Where but one set of feeders is run out from the station, this may be readily accomplished by the use of over-compounded dynamos, adjusted to give an increase of voltage equal to the drop in the feeders at different loads. Again, the field of a shunt-wound generator may be controlled by hand, the pressure at the feeding points being indicated by a voltmeter connected to pilot wires running from the feeding point back to the station.

When the system is more extensive, separate regulation of different feeders is necessary. A variable resistance may be placed in series with separate feeders, but this is undesirable on account of a constant loss of energy. Feeders may be connected in along a system of mains and one or more of these switched in or out of service as the load changes. Bus-bars giving different voltages may be aranged so that the feeders can be changed to a higher voltage bar as the load increases. Boosters—series dynamos—may be connected in series with separate feeders and these may be arranged to regulate the voltage automatically. The use of boosters is not to be recommended except for a few very long feeders, and then the total capacity of boosters should equal but a small percentage of the station output if the efficiency of the system as a whole is to remain high. Fig. 13 is a diagram of a system using different methods of voltage regulation.

Alternating-Current Systems of Distribution may be classified in a manner similar to direct-current systems, that is, as series and parallel systems; but in addition to these we have a classification depending on the number of phases used, such as *single-phase*, *quarter- or two-phase* and *three-phase systems.*

The Series System may consist of a simple series circuit fed by a constant-current generator, or it may be fed by a constant-current transformer, the primary of which is supplied with a constant potential, the secondary furnishing a constant current. For a description of such a transformer, see "Electric Lighting". Again, the current may be maintained constant by means of a constant-current regulator, such as is described in "Electric Lighting". Constant-current alternators are seldom used, the two latter forms of regulation being applied to most series installations. The principal application of series alternating-current systems is to street-lighting. Parallel-series alternating-current systems are sometimes used for street-lighting with incandescent lamps.

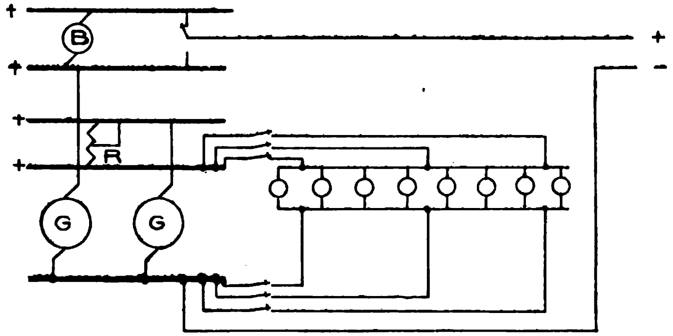
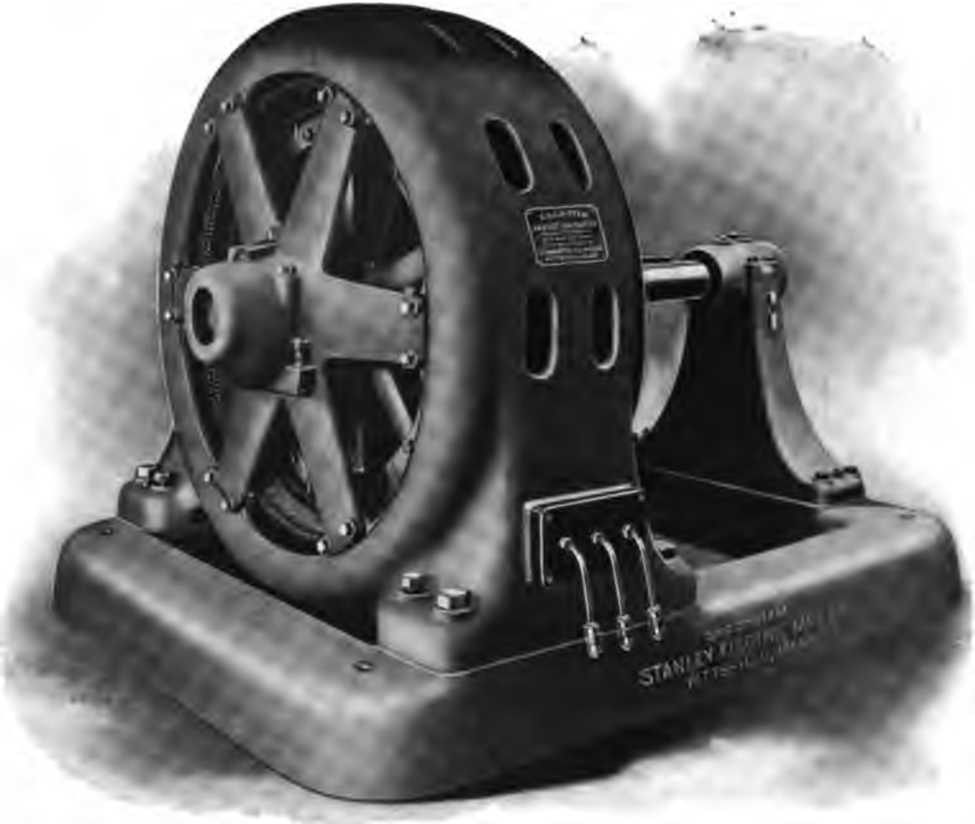


Fig. 13.

Parallel Systems, using alternating current are also analogous to parallel systems using direct current, though the receivers, especially if lamps, are seldom connected directly to the leads coming from the station, but are fed from the secondaries of constant-potential transformers, which are connected to the lines in parallel, and step down the voltage. The readiness with which the voltage of such systems may be changed by means of suitable transformers is the chief advantage of the single-phase systems. The voltage may be generated at, or transformed up to, a high value at the station, transmitted over a considerable distance over small conductors with a small loss of energy, and then transformed to the desired value for the connected units. Transformers may be readily constructed to furnish voltage for a three-wire secondary distribution. Fig. 14 is a diagram of a single-phase system supplying power to both two-wire and three-wire systems. Two separate transformers are used for obtaining the three-wire system, in one case, and a transformer, supplied with a tap connected to the middle point of the secondary, is used in the other case.

The regulation of voltage for alternating-current systems may be accomplished, as in direct-current installations, by means of compounding ("composite-wound alternators"), hand regulation, or resistance or reactance connected in series with the feeders. In addition, the feeders may be controlled by means of special regulators such as the Stillwell Regulator, or the "C R" Regulator, which consist of transformers with the primary coil connected across the line and the secondary in series with the line, and so arranged that the number of turns in one or both windings may be varied; other forms of regulators are the magnetic regulator and the induction regulator.

Polyphase Systems. Polyphase systems of distribution are used where motors are to be run from the circuits; also for long-distance transmission lines partly on account of the saving in copper. Polyphase generators may be constructed more cheaply, for a given output, than single-phase machines because of a better utilization of the winding space on the armature; while single-phase motors, except in small sizes, or series motors as applied to railway work, are not entirely satisfactory. Two-phase and three-phase systems are the only ones that are in common use for power transmission, three phases being used for long-distance transmission lines. Six phases are used for rotary converters only, the capacity of the machines being greatly increased when connected six-phase.



S. K. C. INDUCTION MOTOR WITH OUTBOARD BEARING

The amount of copper required for the different systems, assuming the weight of copper for a single phase two-wire system to be 100%, is as follows:

Single-phase two-wire systems	100 per cent
" " three-wire " (Neutral wire same size as outside wires)	37.5 "
Two-phase four-wire system	100 "
" " three-wire "	72.9 "
Three-phase three-wire system	75 "
" " four-wire "	33.3 "

This assumes the voltage on the receivers to be the same in every case, the maximum voltage having different values, depending on the system used. The three-phase three-wire system is preferable to the two-phase three-wire system for most purposes. In the three-phase four-wire system the maximum voltage is $\sqrt{3}$ times the voltage on the receivers. Were the same maximum voltage allowable as in the three-phase three-wire system, the amount of copper for the three-phase four-wire system would be $\frac{4}{3}$ that required for the three-phase three-wire system. Fig. 15 shows, diagrammatically, the connections of the different systems.

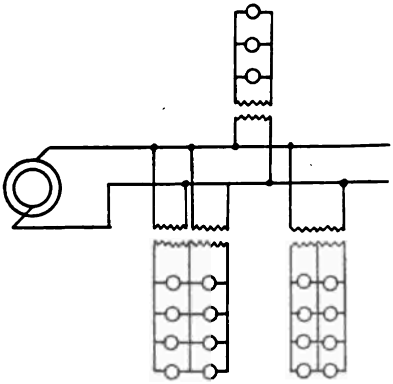


Fig. 14.

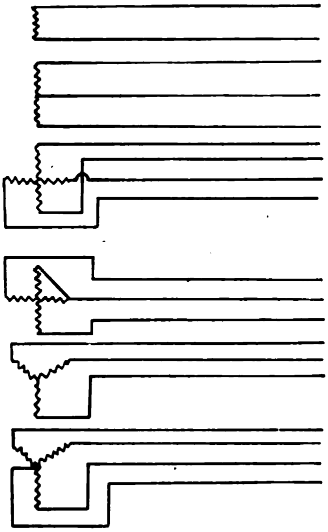


Fig. 15.

As an example of the way in which the relative amounts of copper are calculated, take the three-phase three-wire system. Assume the amount of power transmitted to be P and the percentage loss of energy to be p. Let E = the voltage on the receiver, I = the current flowing in a single conductor, single-phase system, and I′ = current in a single conductor, three-phase system. We have for the single-phase two-wire system,

$$P = IE,$$

for the three-phase three-wire system,

$$P = \sqrt{3}\, I'E$$
$$IE = \sqrt{3}\, I'E.$$
$$I' = \frac{I}{\sqrt{3}}$$

The loss in energy in the two-wire system $= p\,P = 2\,I^2R$, when R = resistance of one conductor. The loss in energy in the three-phase system $= p\,P = 3\,I'^2R'$.

Substituting $\frac{I}{\sqrt{3}}$ for I′, we have

$$2\,I^2R = \frac{3\,I^2R'}{3} \text{ or } 2\,R = R'.$$

The amount of copper is inversely proportional to the resistance of the conductor, so that if W = weight of one conductor for single-phase system and W′ = weight of one conductor for three-phase system, W = 2 W′.

Two conductors are required in the first case = 2 W.

Three conductors are required in the second case = 3 W′.

$$3\,W' = \tfrac{3}{2}\,W.$$
$$2\,W = 2\,W.$$
$$\frac{3\,W'}{2\,W} = \frac{\frac{3}{2}\,W}{2\,W} = \tfrac{3}{4} = 75\%.$$

TRANSMISSION LINES.

Capacity. Conductors used for the transmission of power form, with their metallic shields, with the ground, or with neighboring conductors, condensers, which, when the line is long, have an appreciable capacity. The capacity of circuits is quite readily calculated, the following formula applying to individual cases.

TABLE IV.

Capacity in Micro-Farads Per Mile of Circuit for Three-Phase System.

Size B. & S.	Diam. in inch.	Distance A in inches.	Capacity C in M. F.	Size B. & S.	Diam. in inch.	Distance A in inches.	Capacity C in M. F.
0000	.46	12	.0226	4	.204	12	.01874
		18	.0204			18	.01726
		24	.01922			24	.01636
		48	.01474			48	.01452
000	.41	12	.0218	5	.182	12	.01830
		18	.01992			18	.01690
		24	.01876			24	.01602
		48	.01638			48	.01426
00	.365	12	.0124	6	.162	12	.01788
		18	.01946			18	.01654
		24	.01832			24	.01560
		48	.01604			48	.0140
0	.325	12	.02078	7	.144	12	.01746
		18	.01898			18	.01618
		24	.01642			24	.01538
		48	.01570			48	.01374
1	.289	12	.02022	8	.128	12	.01708
		18	.01952			18	.01586
		24	.01748			24	.01508
		48	.0154			48	.01350
2	.258	12	.01972	9	.114	12	.01660
		18	.01818			18	.01552
		24	.01710			24	.01478
		48	.01510			48	.01326
3	.229	12	.01938	10	.102	12	.01636
		18	.01766			18	.01522
		24	.01672			24	.01452
		48	.01480			48	.01304

$$C = \frac{38.83\, k\, 10^{-3}}{\log \frac{D}{d}} \text{ per mile.}$$

Insulated cable with lead sheath.

$$C = \frac{38.83 \times 10^{-3}}{\log \frac{4h}{d}} \text{ per mile.}$$

Single conductor with earth return.

$$C = \frac{19.42 \times 10^{-3}}{\log \frac{2A}{d}} \text{ per mile of circuit.}$$

Parallel conductors forming a metallic circuit.

C = Capacity in micro-farads. (Divide by 1,000,000 to give capacity in farads.)

k = specific inductive capacity of insulating material = 1 for air = 2.25 to 3.7 for rubber.

D = inside diameter of lead sheath.

d = diameter of conductor.

h = distance of conductors above ground.

A = distance between wires.

Common logarithms apply to these formulæ and C for a metallic circuit is the capacity between wires.

TABLE V.

Inductance Per Mile of Three-Phase Circuit.

Size B. & S.	Diameter in inch.	Distance *d* in inches.	Self-inductance L henrys.	Size B. & S.	Diameter in inch.	Distance *d* in inches.	Self-inductance L henrys.
0000	.46	12	.00234	4	.204	12	.00280
		18	.00256			18	.00300
		24	.00270			24	.00315
		48	.00312			48	.00358
000	.41	12	.00241	5	.182	12	.00286
		18	.00262			18	.00307
		24	.00277			24	.00323
		48	.00318			48	.00356
00	.365	12	.00248	6	.162	12	.00291
		18	.00269			18	.00313
		24	.00285			24	.00329
		48	.00330			48	.00369
0	.325	12	.00254	7	.144	12	.00298
		18	.00276			18	.00310
		24	.00293			24	.00336
		48	.00331			48	.00377
1	.289	12	.00260	8	.128	12	.00303
		18	.00281			18	.00325
		24	.00308			24	.00341
		48	.00338			48	.00384
2	.258	12	.00267	9	.114	12	.00310
		18	.00288			18	.00332
		24	.00304			24	.00348
		48	.00314			48	.00389
8	.229	12	.00274	10	.102	12	.00318
		18	.00294			18	.00340
		24	.00310			24	.00355
		48	.00351			48	.00396

If the capacity be taken between one wire and the neutral point of a system, or the point of zero potential, the capacity is given as:

$$C \text{ (in micro-farads)} = \frac{.0776}{2 \log \frac{2A}{d}} \text{ per mile of } \textit{circuit.}$$

Table IV gives the capacity, to the neutral point, of different size wire used for three-phase transmission lines.

The effect of this capacity is to cause a charging current, 90° in advance of the impressed pressure, to flow in the circuit, and the regulation of the system is affected by this charging current as will be seen later. Capacity may be reduced by increasing the distance between conductors or in lead-sheathed cables, by using an insulating material having a low specific inductive capacity, such as paper.

Inductance. The self-inductance of lines is very readily calculated. Following is a formula applicable to copper or aluminum conductors:

$L = .000558 \left[2.303 \log \left(\frac{2A}{d}\right) + .25\right]$ per mile of *circuit* when L = inductance of a loop of a three phase circuit in henrys. The inductance of a complete circuit, single phase, is equal to the above value multiplied by $2 \div \sqrt{3}$.

Self-inductance is reduced by decreasing the distance between wires and it disappears entirely in concentric conductors. Subdividing the conductors decreases the drop in voltage due to self-inductance but it complicates the wiring. Circuits formed of conductors twisted together have very little inductance. When alternating-current wires are run in iron pipes, both wires of the circuit must be run in the same pipe, inasmuch as the self-inductance depends on the number of magnetic lines of force passing between the conductors or threading the circuit, and this number will be increased when iron is present between the conductors.

The effect of self-inductance in a circuit is to cause the current to lag behind the impressed voltage and it also increases the impedance of the circuit.

The effect of self-inductance may be neutralized by capacity or *vice-versa*. The relative value of the two must be as follows:

$C = \frac{1}{(2\pi f)^2 L}$ when C and L are in farads and henrys respectively, and f is the frequency of the system.

Mutual-Inductance. By mutual-inductance is meant the inductive effect one circuit has on another separate circuit, generally a parallel circuit in power transmission. An alternating current flowing in one circuit sets up an electromotive force in a parallel circuit which is opposite in direction to the E.M.F. impressed on the first circuit, and is proportional to the number of the lines of force set up by the first circuit which thread the second circuit.

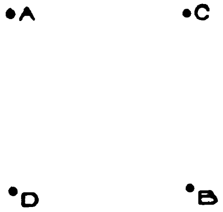


Fig. 16.

The effects of mutual inductance may be reduced by increasing the distance between the circuits, the distance between wires of a circuit remaining the same. This is impractical beyond a

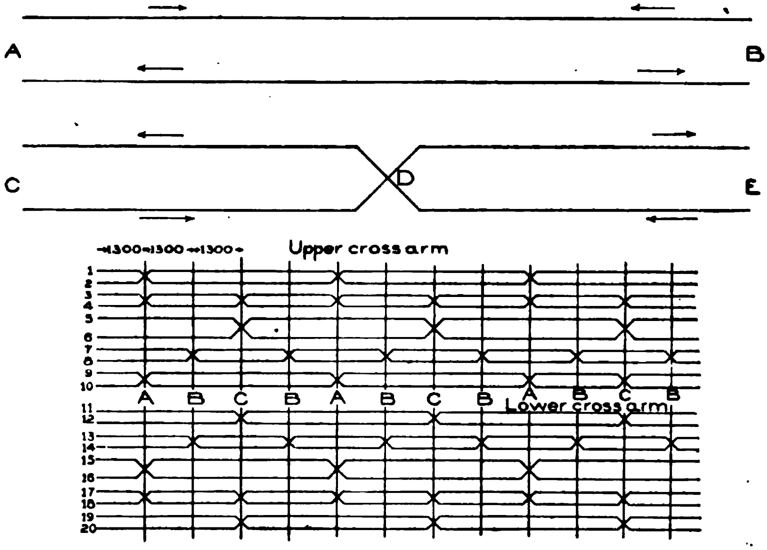


Fig. 17.

certain extent, if the circuits are to be run on the same pole line, so that a special arrangement of the conductors is necessary.

Figs. 16 and 17 show such special arrangements. In Fig. 16 AB forms the wires of one circuit and CD the wires of the other circuit. Lines of force set up by the circuit AB do not thread the circuit CD, provided A B C and D are arranged at the corners of a square so that there is no effect on the circuit CD. In Fig. 17 assume an E.M.F. to be set up in the portion of the circuit CD in the direction of the arrows. The E.M.F. in the section DE will then be in the direction of the arrows shown and the effects on the circuit AB will be neutralized, provided the transposition, as the crossing of the conductors is called, is made at the middle of the line. Such transpositions are made at frequent intervals on transmission lines to do away with the effects of mutual inductance which, at times, might be considerable. When several circuits are run on the same pole line, these transpositions must be made in such a manner that each circuit is transposed in its relation to the other circuits. Thus in Fig. 17 is also shown the transposition of the circuits of a line composed of ten two-wire circuits.

CALCULATION OF ALTERNATING-CURRENT LINES.

In dealing with alternating currents, Ohm's law can be applied only when all of the effects of inductance and capacity have been eliminated, and, since this can seldom be accomplished, a new formula must be used which takes such capacity and inductance effects into account. Not only the inductance or capacity of the line itself must be considered, but the nature of the receiver must be taken into account as well, when the regulation of the system as a whole is being considered. The following quantities must be known in the complete solution of problems relating to alternating-current systems.

1. Frequency of the current used.
2. Self-induction and capacity of the receivers.
3. Self-induction and capacity of the lines.
4. Voltage of, and current flowing in, the lines.
5. Resistance of the various parts.

Following is a set of formulæ and an appropriate table for calculating transmission lines proper when using direct or alternating current and for frequencies varying from 25 to 125, and for single and polyphase currents. This table is issued by the General Electric Company.

GENERAL WIRING FORMULA.

Area of conductor, Circular Mils $= \frac{D \times W \times C'}{p \times E^2}$

Current in main conductors $= \frac{W \times T}{E}$

W = Total watts *delivered.*

D = Distance of transmission (one way) in feet.

p = Loss in line in per cent of power *delivered*, that is, of W.

E = Voltage between main conductors at *receiving* or *consumer's* end of circuit.

For continuous current $C' = 2{,}160$, $T = 1$, $B = 1$, and $A = 6.04$.

Volts loss in lines $= \frac{p \times E \times B}{100}$

Lbs. copper $= \frac{D^2 \times W \times C' \times A}{p \times E^2 \times 1{,}000{,}000}$

The following formula will also be found convenient for calculating the copper required for long-distance three-phase transmission circuits:

$$\text{Lbs. Copper} = \frac{M^2 \times \text{K.W.} \times 300{,}000{,}000}{p \times E^2}$$

M is the distance of transmission in miles, K.W. the power delivered in kilowatts, and the power factor is assumed to be approximately 95%.

APPLICATION OF FORMULÆ.

"The value of C′ for any particular power factor is obtained by dividing 2,160, the value for continuous current, by the square of that power factor for single-phase, by twice the square of that power factor for three-wire three-phase, or four-wire two-phase. The value of B depends on the size of wire, frequency, and power factor. It is equal to 1 for continuous current, and for alternating current with 100 per cent power factor and sizes of wire given in the following table of wiring constants.

"The figures given are for wires 18 inches apart, and are sufficiently accurate for all practical purposes provided the displacement in phase between current and E.M.F. at the receiving end is not

TABLE VI.

System.	Values of A.	Values of C'.				
		Per Cent Power Factor.				
		100	95	90	85	80
Single-phase	6.04	2,160	2,400	2,660	3,000	3,380
Two-phase (four-wire)	12.08	1,080	1,200	1,330	1,500	1,690
Thre-phase (three-wire)	9.06	1,080	1,200	1,330	1,500	1,690

System.	Values of T.				
	Per Cent Power Factor,				
	100	95	90	85	80
Single-phase	1.00	1.05	1.11	1.17	1.25
Two-phase (four-wire)	.50	.53	.55	.59	.62
Three-phase (three-wire)	.58	.61	.64	.68	.72

No. of Wire. B. & S. Gauge.	VALUES OF B.							
	60 Cycles.				125 Cycles.			
	Per Cent Power Factor.				Per Cent Power Factor.			
	95	90	85	80	95	90	85	80
0000	1.62	1.84	1.99	2.09	2.35	2.86	3.24	3.49
000	1.49	1.66	1.77	1.95	2.08	2.48	2.77	2.94
00	1.34	1.52	1.60	1.66	1.86	2.18	2.40	2.57
0	1.31	1.40	1.46	1.49	1.71	1.96	2.13	2.25
1	1.24	1.30	1.34	1.36	1.56	1.75	1.88	1.97
2	1.18	1.23	1.25	1.26	1.45	1.60	1.70	1.77
3	1.14	1.17	1.18	1.17	1.35	1.46	1.53	1.57
4	1.11	1.12	1.11	1.10	1.27	1.35	1.40	1.43
5	1.08	1.08	1.06	1.04	1.21	1.27	1.30	1.31
6	1.05	1.04	1.02	1.00	1.16	1.20	1.21	1.21
7	1.03	1.02	1.00	1.00	1.12	1.14	1.14	1.13
8	1.02	1.00	1.00	1.00	1.09	1.10	1.09	1.07
9	1.00	1.00	1.00	1.00	1.06	1.06	1.04	1.02
10	1.00	1.00	1.00	1.00	1.04	1.03	1.00	1.00

No. of Wire B. & S. Gauge.	Area of Wire Circular Mils	Weight of Bare Wire Per 1,000 ft.-lbs.	Resistance of Wire Per 1,000 feet at 25° C. Ohms.	Values of B.							
				25 Cycles.				40 Cycles.			
				Per Cent Power Factor.				Per Cent Power Factor.			
				95	90	85	80	95	90	85	80
0000	212000	641	.0499	1.23	1.29	1.33	1.34	1.52	1.53	1.61	1.67
000	168000	509	.0628	1.18	1.22	1.24	1.24	1.40	1.41	1.48	1.51
00	133000	403	.0794	1.14	1.16	1.16	1.16	1.25	1.32	1.35	1.37
0	106000	320	.0997	1.10	1.11	1.10	1.09	1.19	1.24	1.26	1.28
1	83500	253	.126	1.07	1.07	1.05	1.03	1.14	1.17	1.18	1.17
2	66600	202	.159	1.05	1.04	1.02	1.00	1.11	1.12	1.12	1.10
3	52400	159	.202	1.03	1.02	1.00	1.00	1.07	1.08	1.07	1.05
4	41600	126	.254	1.02	1.00	1.00	1.00	1.05	1.06	1.03	1.00
5	33100	100	.319	1.00	1.00	1.00	1.00	1.03	1.01	1.00	1.00
6	26200	79.5	.403	1.00	1.00	1.00	1.00	1.02	1.00	1.00	1.00
7	20700	62.8	.510	1.00	1.00	1.00	1.00	1.01	1.00	1.00	1.00
8	16600	50.4	.635	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
9	13000	39.4	.813	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10	10400	31.5	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

very much greater than that at the generator; in other words, provided that the reactance of the line is not excessive or the line loss unusually high. For example, the constants should not be applied at 125 cycles if the largest conductors are used and the loss 20% or more of the power delivered. At lower frequencies, however, the constants are reasonably correct even under such extreme conditions. They represent about the true values at 10% line loss, are close enough at all losses less than 10%, and often, at least for frequencies up to 40 cycles, close enough for even much larger losses. Where the conductors of a circuit are nearer each other than 18 inches, the volts loss will be less than given by the formulæ, and if close together, as with multiple-conductor cable, the loss will be only that due to resistance.

"The value of T depends on the system and power factor. It is equal to 1 for continuous current and for single-phase current of 100 per cent power factor. The value of A and the weights of the wires in the table are based on .00000302 pound as the weight of a foot of copper wire of one circular mil area.

"In using the above formulæ and constants, it should be particularly observed that *p* stands for the per cent loss in the line of the *delivered power*, not for the per cent loss in the line of the power at the generator; and that E is the potential at the delivery end of the line and not at the generator.

"When the power factor cannot be more accurately determined, it may be assumed to be as follows for any alternating system operating under average conditions: Incandescent lighting and synchronous motors, 95%; lighting and induction motors together, 85%; induction motors alone, 80%.

"In continuous-current three-wire systems, the neutral wire for feeders should be made of one-third the section obtained by the formulæ for either of the outside wires. In both continuous and alternating-current systems, the neutral conductor for secondary mains and house wiring should be taken as large as the other conductors.

"The three wires of a three-phase circuit and the four wires of a two-phase circuit should all be made the same size, and each conductor should be of the cross-section given by the first formula".

Numerical examples of the application of this table, as well as of other formulæ, are given later.

A better idea of the way in which the different quantities involved affect the regulation of an alternating-current line may be obtained from graphical representation or from formulæ which are not so empirical. Before taking up other methods of calculation, however, let us consider the meaning of power factor.

By **power factor** we mean the cosine of the angle by which the current lags behind or leads the electromotive force producing that current. It is the factor by which the apparent watts (volts times amperes) must be multiplied to give true power. The formula for power in a single-phase circuit is then,

Power $=$ IE $\cos\theta$ when θ is the lag or lead angle; and for three-phase circuits, Power $= \text{IE} \cos \theta \sqrt{3}$ when I is the current flowing in a single conductor.

For two-phase circuits, balanced load, this becomes,

Power $= 2\ \text{IE} \cos \theta$; and,

Power $= 2 \sqrt{3}\ \text{IE} \cos \theta$, for six-phase circuits.

For single and three-phase circuits E is the voltage between lines. For two-phase circuits it is the voltage across either phase, and for six-phase circuits it is the voltage across one phase of what corresponds to a three-phase connection.

Considering the formula for single phase, we find that the current flowing in the line may be taken as made up of two components, one in phase with the voltage and one 90° out of phase, lagging, or leading, depending on conditions. In Fig. 18 let OE equal the impressed pressure and OC the current flowing. $\theta =$ angle of lag. The current OC may be resolved into two components, one in phase with OE = OB, and one 90 degrees behind OE = BC.

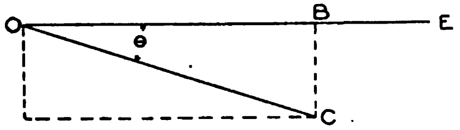


Fig. 18.

OB = OC cos θ and is known as the active component of the current.

BC = OC sin θ and is known as the wattless component of the current.

The capacity and inductance are distributed throughout the line, that is, the line may be considered as made up of tiny condensers and reactance coils, connected at short intervals as shown in Fig. 19. Considering the inductance and capacity as distributed in this manner, the regulation of a system may be calculated, but the process is very difficult, and simpler methods, which give very close results, have been adopted for practical work. Probably the

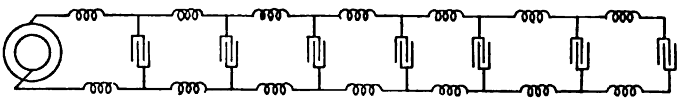


Fig. 19.

methods presented by Perrine and Baum are as simple as any except those based on purely empirical formulæ.

Tables giving the capacity and inductance of lines, together with the formulæ for the calculation of these quantities, have already been given. It has also been stated that the effect of the capacity of a line is to cause a charging current to flow in the line, this current being 90° in advance of the impressed voltage. The value of this charging current is:

$$\text{Charging current per wire} = \frac{E \times C \times 2\,\pi \times f}{2 \times 10^6}, \text{ single-phase.}$$

C = capacity in micro-farads of one wire to neutral point.
f = frequency of the circuit.
E = voltage between wires.

Charging current, three-phase, $= \frac{2}{\sqrt{3}}$ or $1.155 \times$ charging current, single-phase.

Since the voltage across the lines is not the same all along the line, the value of the charging current will not be the same, but the error introduced by assuming it to be constant is not great. For our calculation, then, we assume that the charging current in an open-circuited line is constant throughout its length, and also that the capacity of the line may be taken as concentrated at the center of the line.

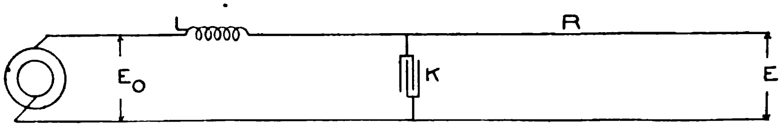


Fig. 20.

Consider a single-phase line such as is shown diagrammatically in Fig. 20.

Let E_0 = the voltage at the generator end of the line.
E = the voltage at the receiver.
L = self induction of the line.
I_c = charging current per wire.
I = current flowing in the line due to the load on the line.

θ = angle by which the load current differs from the impressed voltage.

R = resistance of the line.

e = drop in voltage in the line.

$\omega = 2\pi f$.

$+j$ is a symbol indicating that the current is 90° in advance of the pressure.

$-j$ indicates that the current is 90° behind the pressure.

The expression, $\sqrt{R^2 + (2\pi f L)^2} = \sqrt{R^2 + \omega^2 L^2}$ may be represented by $R + jL\omega$, the factor $+j$ indicating that the square root of the sum of the squares of these two quantities must be taken to obtain the numerical result. The quantity j^2 may be considered as -1.

Taking the capacity of the line and considering it as a condenser located at the middle of the line, we may assume the charging current as flowing over only one-half of the line, or one-half the charging current may be considered as flowing over all of the line.

The impedance of the line is equal to $\sqrt{R^2 + \omega^2 L^2} = R + jL\omega$.

The power factor of the load = $\cos\theta$.

The active component of the current is $I\cos\theta$.

The wattless component of the current is $-jI\sin\theta$ ($-j$ indicating that the current lags 90° behind the pressure).

The charging current may be represented by $+j\frac{I_c}{2}$.

Then the drop due to the active component of the load is

$$I\cos\theta\,(R + jL\omega).$$

The drop due to the wattless component of the load is

$$-jI\sin\theta\,(R + jL\omega).$$

The drop due to the charging current is $+j\frac{I_c}{2}(R + jL\omega)$

The total drop is equal to the sum of these three values = e, so that,

$$E_0 = E + e = I\cos\theta\,(R + jL\omega) - jI\sin\theta\,(R + jL\omega) + j\frac{I_c}{2}(R + jL\omega)$$

Expanding this and substituting -1 for j^2 we have,

$$E_o = E + I\cos\theta\, R + jI\cos\theta\, L\omega - jI\sin\theta\, R + I\sin\theta\, L\omega$$
$$+ j\frac{I_c}{2} R - \frac{I_c}{2} L\omega.$$

Referring to Fig. 21 we have these various values plotted graphically.

$oa = E,\qquad ab = -j\frac{I_cR}{2},\qquad bc = -\frac{I_cL\omega}{2}$

$cd = +I\cos\theta\, R,\qquad de = +jI\cos\theta\, L\omega,$

$ef = -jIR\sin\theta,\qquad fg = +IL\omega\sin\theta,$

$og = E_o.$

ab is plotted 90° in advance of *oa* on account of the symbol $+j$.

bc is plotted in the opposite direction from *oa* on account of the negative sign.

ef is plotted downward on account of the symbol $-j$.

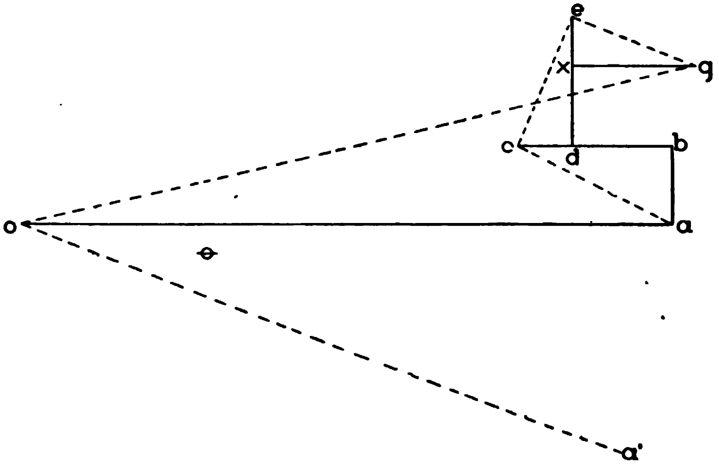


Fig. 21.

If we let *oa'*, Fig. 21, represent the current vector, then θ = angle of lag, and *eg* which equals IR is plotted parallel to *oa'* and $ce = IL\omega$ is plotted perpendicular to *oa'*.

It is seen from this that the charging current tends to produce a rise in E.M.F. instead of a drop in pressure.

The above takes into account only the constants of the line. In order to determine the regulation of a complete system, the resistance, capacity, and inductance of the translating devices must be considered as well. In Fig. 22 is shown a diagram of a complete system with both step-up and step-down transformers connected in service. The charging current may be considered as flowing through half of the system only, namely, the generator, the step-up transformers, and one-half of the line.

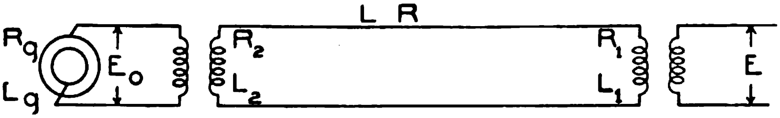


Fig. 22

Let R_1 = the equivalent resistance of the step-down transformers.

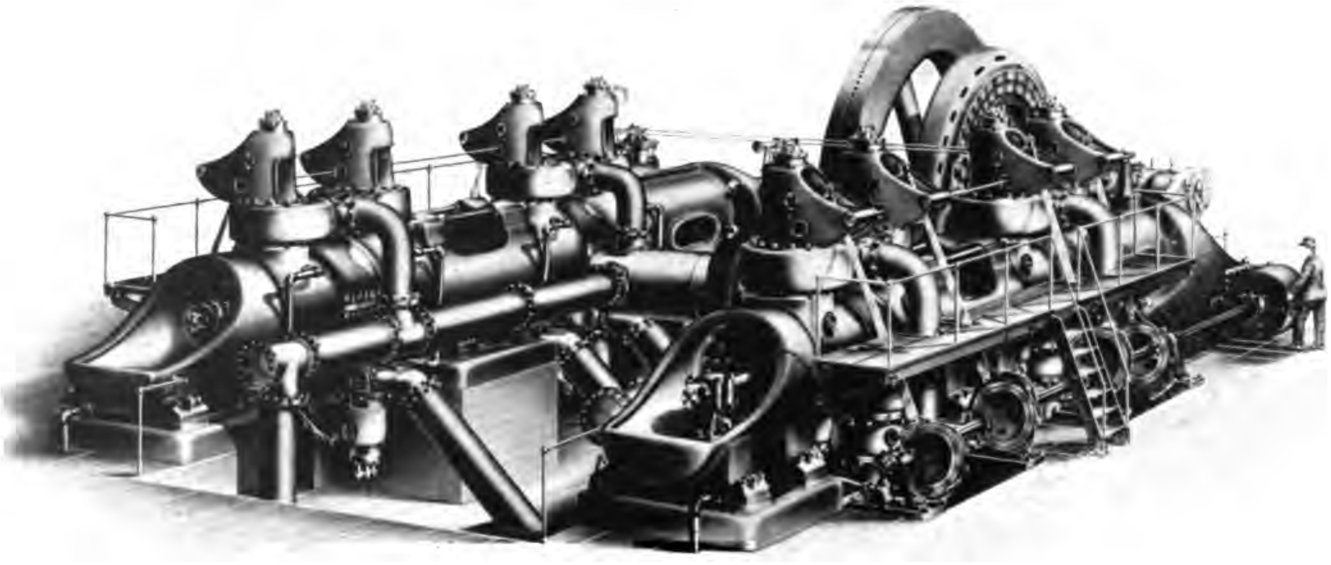
R_2 = the equivalent resistance of the step-up transformers.

L_1 = inductance of the step-down transformers.
L_2 = inductance of the step-up transformers.
R_g = equivalent resistance of the generators.
L_g = equivalent inductance of the generators.
R = resistance of the line.
L = inductance of the line.
$L_T = L_1 + L_2 + L_g + L.$
$R_T = R_1 + R_2 + R_g + R.$

All quantities should be converted into their equivalent values for the full line pressure. Thus the generator and receiver voltages should be multiplied by the ratio of transformation of the step-up and step-down transformers, respectively, to change them to the full line pressure. The resistance and inductance of the transformers must include the resistance and inductance of both windings, and the value must correspond to the line voltage. Thus the resistance of the step-up transformers will be $r_1 n^2 + r_2$,

when r_1 = resistance of primary coil,
r_2 = resistance of secondary coil,
n = the ratio of transformation. In the same way, the

equivalent resistance of the step-down transformers will be $r_1 + n^2 r_2$. The generator resistance and inductance must be multiplied by n^2 to bring them to equivalent values for the full line pressure.



WESTINGHOUSE HORIZONTAL DOUBLE-ACTING GAS-DRIVEN GENERATING UNIT. TWIN TANDEM TYPE GAS ENGINE AND DIRECT-CONNECTED GENERATOR

800 H. P. Unit, Power Plant of Carnegie Steel Co., Bessemer, Pa.

Our formula then becomes:—

$$E_0 = E + I\cos\theta\,(R_T + jL_T\omega) - jI\sin\theta\,(R_T + jL_T\omega) + jI_c\left[\left(\frac{R}{2} + R_2 + R_g\right) + j\omega\left(\frac{L}{2} + L_2 + L_g\right)\right]$$

Plotted graphically we have, Fig. 21:

$oa = E$

$ab = j\,I_c\left(\frac{R}{2} + R_2 + R_g\right)$

$bc = -\,I_c\,\omega\left(\frac{L}{2} + L_2 + L_g\right)$

$cd = I\cos\theta\,R_T$

$de = j\,I\cos\theta\,L_T\,\omega$

$ef = -j\,I\,R_T\sin\theta$

$fg = I\,L_T\,\omega\sin\theta$

$og = E_0$

The numerical value of E and E_0 may be determined, from a diagram such as is shown in Fig. 21, when constructed to scale; or it may be calculated analytically, remembering that the quantities affected by j are to be combined, geometrically, with the quantities not affected by the symbol.

The above formulæ apply to single-phase circuits directly. If to be used for the calculation of three-phase circuits, the following points must be observed:

1. Charging current (I_c) three-phase $= \frac{2}{\sqrt{3}} \times$ charging current single-phase.
2. The voltage should, preferably, be considered as the voltage between one line and the neutral point. The voltage to the neutral point will be the line voltage divided by $\sqrt{3}$.
3. The resistance of one line only is considered, not the resistance of a loop.
4. The inductance of one line only is used. The inductance of one line equals the inductance of a loop divided by $\sqrt{3}$.

Examples of Alternating-Current Line Calculation.

1. What is the capacity, in micro-farads, between wires of a single-phase transmission line 10 miles in length composed of number 6 copper wire spaced 15 inches apart? What is the capacity to the neutral point?

$$C \text{ in farads} = \frac{19.42 \times 10^{-9}}{\log \frac{2A}{d}} \text{ per mile of circuit.}$$

$A = 15$ inches

$d = .162$ inches.

$\frac{2A}{d} = 185$

$\log 185 = 2.2672$

$$\text{C in farads} = \frac{19.42 \times 10^{-9}}{2.2672} \times 10 = .000000085$$

$$\text{C in micro-farads} = .000000085 \times 1{,}000{,}000 = .085$$

$$\text{C in micro-farads with respect to the neutral point} = \frac{.0776}{2 \log \frac{2A}{d}}$$

$$\text{C in micro-farads} = \frac{.0776}{2 \times 2.2672} \times 10 = .171$$

This shows that the capacity to the neutral point is twice the capacity to the other wire.

2. What is the self inductance of the above circuit?

$$L = .000558 \times \frac{2}{\sqrt{3}}\left(2.303 \log \frac{2A}{d} + .25\right) \text{ per mile of circuit.}$$

$$L = .000644\,(2.303 \times 2.2672 + .25) \times 10$$

$$= .000644 \times 5.47 \times 10 = .0352 \text{ henrys.}$$

3. A circuit has a capacity of .2 micro-farads. What must be the value of its inductance to compensate for this capacity at 60 cycles?

$$C = \frac{1}{(2\pi f)^2 L}$$

$$C = .0000002 \text{ farads}$$

$$(2\pi f)^2 = (2 \times 3.1416 \times 60)^2 = 142122$$

$$.0000002 = \frac{1}{142122\, L.}$$

$$L = 1 \div (142122 \times .0000002) = 35.2 \text{ henrys}$$

4. It is desired to transmit 1,000 K.W. a distance of 25 miles at a voltage of 20,000, a frequency of 60 cycles, and a power factor of 85%. Transmission is to be a three-phase three-wire system. Allowing 10% loss of delivered power in the line, required:

- **a** Area of conductor.
- **b** Current in each conductor.
- **c** Volts lost in line.
- **d** Pounds of copper.

a Circular mils $= \dfrac{D \times W \times C'}{p \times E^2}$

$$D = 25 \times 5{,}280 = 132{,}000$$

$$W = 1{,}000 \times 1{,}000 = 1{,}000{,}000$$

$C' = 1{,}500$ for three-phase three wire system and 85% power factor.

$p = 10$

$E = 20{,}000 \quad E^2 = 400{,}000{,}000$

$$\text{Circular mils} = \frac{132000 \times 1000000 \times 1500}{10 \times 400000000} =$$

$$\frac{132 \times 1500}{4} = 49{,}500.$$

Number 3 wire has a cross-section of 52,400 cir. mils.

b Current in each conductor $= \dfrac{W \times T}{E} = 34.$

$T = .68$ for three-phase system, 85% power factor.

c Volts lost in line $= \dfrac{p \times E \times B}{100}$

$B = 1.18$ for number 3 wires, 60 cycles and 85% power factor.

$$\text{Volts lost} = \frac{10 \times 20{,}000 \times 1.18}{100} = 2360$$

d Pounds copper $= \dfrac{D^2 \times W \times C' \times A}{p \times E^2 \times 1{,}000{,}000}$; or it may be calculated directly from the weight of wire given in the tables after the size of wire has been determined by other formulæ. Thus 75 miles of number 3 wire is required. This weighs 159 pounds per 1,000 feet.

$$159 \times 5.280 \times 75 = 62{,}964 \text{ pounds.}$$

5. A single-phase line 20 miles in length is constructed of number 000 wire strung 24 inches apart. It is desired to transmit 500 K.W. over this line at a frequency of 25 cycles and a power factor of 80%, the voltage at the receiver end being 25,000. Considering the line drop only, what must be the voltage at the generator end of the line?

$$E_0 = E + I\cos\theta\, R + j\, I\cos\theta\, L\omega - j\, I\sin\theta\, R + I\sin\theta$$

$$L\omega + j\frac{I_c}{2}R - \frac{I_c}{2}L\omega.$$

$E = 25{,}000$

$$I = \frac{500{,}000}{25{,}000 \times .80} = 25 \quad (\text{Power} = IE\cos\theta)$$

$\cos\theta = .80$

$\sin\theta = .60$ (from trigonometric tables)

R = resistance of 40 miles of number 000 wire = 14.56 ohms at 50° C.

$$L = .00277 \times \frac{2}{\sqrt{3}} \times 20 = .064 \text{ (calculated from Table V).}$$

$$\omega = 2\pi f = 2\pi \times 25 = 157$$

$$I_c = \frac{E \times C \times 2\pi \times f}{2 \times 10^6} = \frac{25{,}000 \times .3752 \times 157}{2 \times 1{,}000{,}000} = .736 \text{ Amp.}$$

C = .3752 (Table IV or calculated).

Substituting these values in the above formula we have,

$$E_0 = 25{,}000 + 291.2 + j200.8 - j218.4 + 150.6 + j5.36 - 3.7$$

$$E_0 = 25{,}000 + 291.2 + 150.6 - 3.7 + j(200.8 - 218.4 + 5.36)$$

$$E_0 = 25{,}000 + 291.2 + 150.6 - 3.7 - j(218.4 - 200.8 - 5.36)$$

$$E_0 = \sqrt{(25{,}000 + 291.2 + 150.6 - 3.7)^2 + (218.4 - 200.8 - 5.36)^2}$$

Since the symbol j indicates that the quantities must be combined geometrically.

$$E_0 = \sqrt{(25{,}438.1)^2 + (12.24)^2} = 25{,}438.1 \text{ volts.}$$

6. A three-phase line 20 miles in length is constructed of number 000 wire strung 24 inches apart. We wish to transmit 1,000 K.W. over this line at a frequency of 25 cycles and a power factor of 85%, the voltage at the receiving end being 2,000. Three Y-connected 500 K.W. transformers having a ratio of 10 : 1 step the voltage up and down at either end of the line. The resistance of the high-tension winding of each transformer is 4 ohms. The resistance of the low-tension windings is .04 ohms. The inductance of each transformer is 4 henrys. Neglecting the generator constants, what must be the voltage applied to the low-tension windings of the step-up transformers?

$$E_0 = E + I\cos\theta\,(R_T + jL_T\omega) - jI\sin\theta\,(R_T + jL_T\omega) + jI_c \left[\left(\frac{R}{2} + R_2\right) + j\omega\left(\frac{L}{2} + L_2\right)\right]$$

Since this is for a three-phase circuit we will work with the voltage to the neutral point and will change all values to correspond to the line voltage. Hence,

$$\frac{E_0}{\sqrt{3}} \times 10 = \frac{E}{\sqrt{3}} \times 10 + ----------$$

$I = 34$ amperes. Since $\sqrt{3}\,IE \cos\theta = 1{,}000{,}000$

$E = 10 \times 2{,}000 = 20{,}000$

$\cos\theta = .85$

$I = 34.$

R_T = Resistance of one line + equivalent resistance of one transformer at each end of the line.

$$R_T = 7.28 \text{ ohms} + 4 + 100 \times .04 + 4 + 100 \times .04.$$
$$= 23.28 \text{ ohms}.$$
$$L_T = .0554 \div \sqrt{3} + .4 + .4 = .832 \text{ henrys}.$$
$$\omega = 157$$
$$\sin\theta = .52$$

$I_c = .589 \times \frac{2}{\sqrt{3}} = .677$ amp. = charging current single-phase $\times \frac{2}{\sqrt{3}}$.

$$\frac{R}{2} = 3.64$$
$$R_2 = 8$$
$$\frac{L}{2} = .016 \qquad L_2 = .4$$

Substituting these values in our formula we have,

$$\frac{E_0 \times 10}{1.73} = \frac{20{,}000}{1.73} + 672.8 + j\,3774 - j\,411.6 + 2309$$
$$+ j\,7.88 - 44.2$$
$$= 11{,}550 + 672.8 + 2{,}309 - 44.2 + j\,(3{,}774 - 411.6 + 7.88)$$
$$= \sqrt{14{,}487.6^2 + 3370.3^2} = 14{,}874$$
$$E_0 = 2{,}573 \text{ volts}.$$

TRANSFORMERS.

A transformer consists of two coils made up of insulated wire, the coils being insulated from each other and from a core, made up of laminated iron, on which they are placed. One of these coils, known as the primary coil, is connected across the circuit, in constant-potential transformers, and the other coil, known as the secondary coil, is connected to the lamps or motors, or whatever makes up the receivers. As a matter of fact, these coils are each usually made up of several sections. The voltage induced in the secondary windings is equal to the voltage impressed on the primary winding multiplied by the ratio of the number of turns in the secondary to the number in the primary coil, less a certain drop due to impedance of the coils and to magnetic leakage. This drop is negligible on no load. If transformers are used to raise the voltage, they are termed *step-up* transformers. If used to lower the voltage, they are called *step-down* transformers.

Losses of power occurring in transformers are of two kinds namely:

Iron or core losses which are made up of hysteresis and eddy-current losses in the iron making up the core, and

Copper losses which are due to the I^2R losses in the windings with the addition, in some cases, of eddy currents set up in the conductors themselves.

The efficiency of a transformer depends on the value of these losses and may be expressed as the ratio of the watts output to the watts input.

$$\frac{W_s}{W_p} = \frac{W_p - (W_c + W_h + W_e)}{W_p}$$

W_s = watts secondary.
W_p = watts primary.
W_c = copper losses.
W_h = hysteresis losses.
W_e = eddy current losses.

The iron losses remain constant for any given voltage regardless of the load, while the copper losses are proportional to the square of the current. The efficiencies of transformers are high, varying from 94 to 95% at $\frac{1}{4}$ load to 98% at full load for sizes above 25 K.W.

By All-Day Efficiency is meant the efficiency of a transformer, taking into consideration its operation for twenty-four hours, and it is calculated for the ratio of watt-hours output to watt-hours input for this length of time when in actual service. For calculation, the transformer is often assumed to be fully loaded for five hours and run with no load for the remaining nineteen. The all-day efficiency is then determined as follows:

Output, K.W. hours = watts output at full load × 5.

Input, K.W. hours = watts output at full load × 5 + I^2R loss at full load × 5 + core loss at normal voltage × 24.

$$\text{All-day efficiency} = \frac{\text{output, watt-hours}}{\text{input, watt-hours.}}$$

The assumption that a lighting transformer is fully loaded five hours out of the day is not always a correct one. On many circuits from two to three hours of full load would be more nearly the proper value to use in calculating the all-day efficiency.

By Regulation of a transformer is meant the percentage drop in the secondary voltage from no load to full load when normal pressure is impressed on the primary. This drop is due to the IR drop in the windings and to magnetic leakage. In well designed transformers the loss due to magnetic leakage is about 10%, or less, of that due to the resistance drop. For non-inductive load (power factor = unity) the regulation is from 1 to 3% in good transformers. With induction load this is increased to 4 or 5%, or even more.

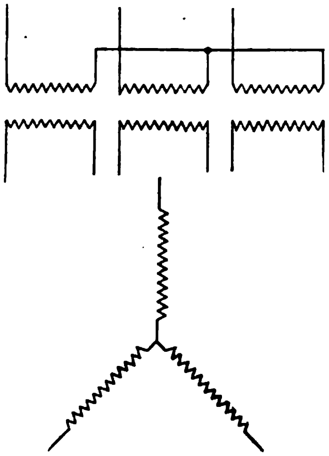
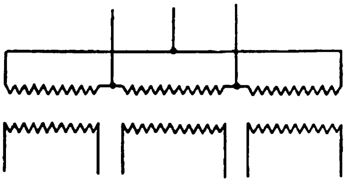


Fig. 23.

Both the efficiency and the regulation should be considered in selecting a transformer for given service. Thus, if a transformer is to be used for lighting, its regulation should be of the best, since drop in voltage due to the transformer is in addition to that due to the conductors. In the same way the regulation of any system as a whole depends to a certain extent on the regulation of the transformer installed.

If the efficiency of a transformer is low, it means a direct loss of considerable energy as well as greater heating of the transformer and consequent deterioration. If a transformer is to be used for lighting purposes, or is lightly loaded, a large portion of the time, a type should be selected which has a relatively low core loss so as to increase the all-day efficiency. If fully loaded all day, the losses should be divided about equally between the copper and the iron losses.

Transformer Connections. Transformers for three-phase work may be connected in two ways. Where three transformers are used, they may be connected in Y or star, that is, with one terminal of each primary brought to a common point and the other terminal connected to a line wire (see Fig. 23), or they may be connected in Δ or mesh when the three primaries are connected in series and the line wires are connected to the three corners of the triangle so formed (see Fig. 24). The secondaries may be connected in Y the same as the primaries or the secondaries may be connected in Y when the primaries are in Δ, or *vice versa.* The voltage relation may be best determined from vector diagrams as shown in Fig. 25, which gives the voltage relation of step-down transformers with a ratio of 10 : 1, when the voltage across the primary lines is 1,000.



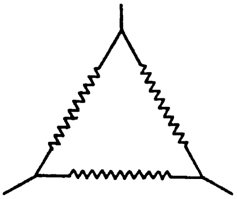


Fig. 24.

Changes may be made from two to three phases, or from three to two phases, with or without a change of voltage, by means of transformers having the required ratio of transformation by use of what is known as the *Scott* connections. Fig. 26 shows such a connection together with a corresponding vector diagram showing the relations when the change is from two to three-phase with a 10 : 1 transformation of voltage. The *main* transformer is fitted with a tap at the middle point of the secondary wiring to which one terminal of the *teaser* transformer is connected. The teaser has a ratio of transformation differing from that of the main transformer, as shown in the figure.

Six Phases are obtained from three phases for use with rotary converters by means of transformers having two secondary windings or by bringing both ends of each winding to opposite points on the rotary-converter winding, utilizing the converter winding for giving the six phases. The latter, shown in Fig. 27, is known as a diametrical connection. When transformers with

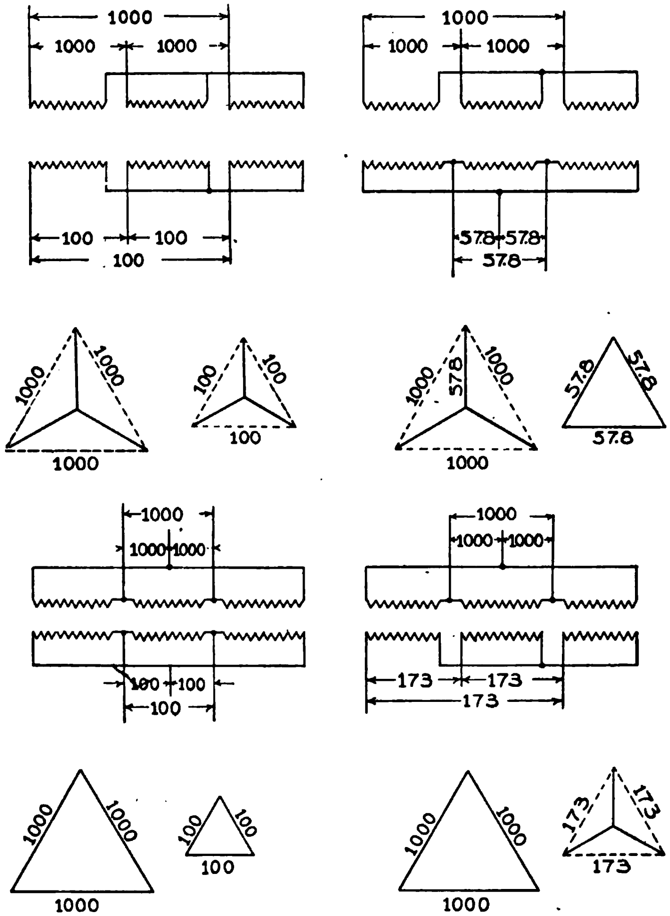


Fig. 25.

two secondaries are used, the secondaries may be connected in six-phase Y or six-phase Δ as shown in Figs. 28 and 29. When the Y-connection is used, the common connection of each set of secondaries is made at the opposite ends of the coils. This leaves the free ends directly opposite or 180° different in phase. The way in which these ends are brought out to give six phases is best illustrated by means of the two triangles arranged as shown in Fig. 30, which have their points numbered corresponding to the connection in Fig. 28. In Fig. 29 one Δ is reversed with respect to the other, and six phases are brought about in this manner.

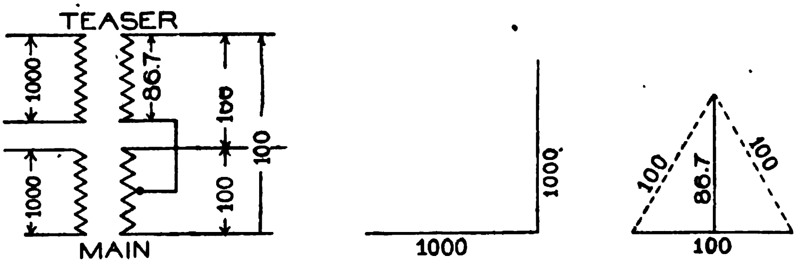


Fig. 26.

Single transformers, constructed for three-phase and six-phase work, are now being manufactured in this country, and they are being used to an increasing extent. They are a little cheaper to build for the same total output, and save floor space, but are not so flexible as three single-phase transformers.

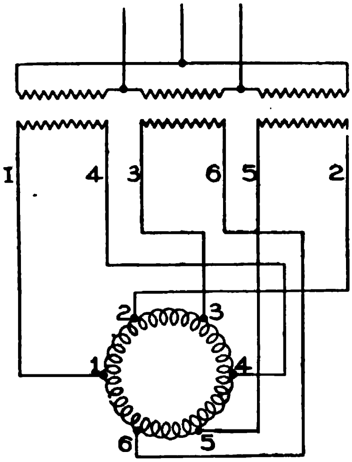


Fig. 27.

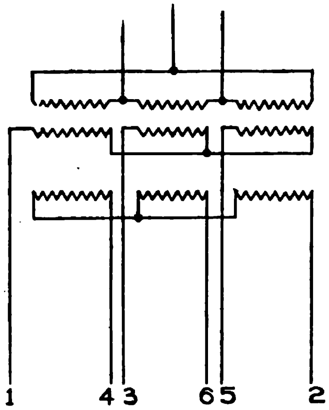


Fig. 28.

Where other conditions allow, a Δ to Δ-connection is preferable, for with this connection, if one transformer is injured, it may be taken out of circuit and the remaining two will maintain the service, and may be loaded up to $\frac{2}{3}$ of the former capacity of the system. In the Y-connection, however, the voltage impressed on the transformer winding is only $\frac{1}{\sqrt{3}} = .58$ times the voltage of the line, thus making it possible to construct a transformer with a fewer number of turns. The windings must be insulated from the case, however, for a potential equal to the line potential, unless the neutral point be grounded when the potential strain to which the transformer is liable to be subjected, under ordinary conditions, is reduced to $\frac{1}{\sqrt{3}}$ of its value when the neutral is not grounded. For small transformers wound for high potential the cost is in favor of the Y-connection.

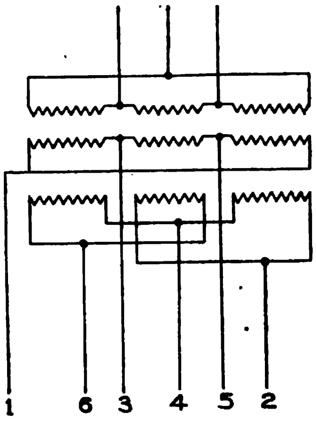


Fig. 29.

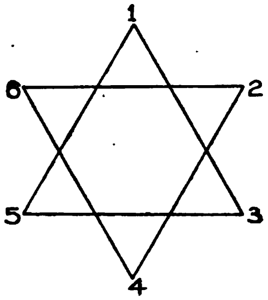


Fig. 30.

Choice of Frequency. The frequencies in extended use at present in this country are 25, 40, and 60 cycles, 25 or 60 cycles being met with more frequently than 40 cycles. Formerly, a frequency of 125 or 133 cycles per second was quite often employed for lighting purposes, but these are no longer considered standard.

The advantages of the higher frequency are:

1. Less first cost and smaller size of generators and transformers for a given output.
2. Better adapted to the operation of arc or incandescent lamps. Lamps, when run below 40 cycles, especially low candle-power incandescent lamps at 110 volts or higher, are liable to be trying to the eyes on account of the flicker.

Its disadvantages are:

1. Inductance and capacity effects are greater, hence a poorer regulation of the voltage. The charging current is directly proportional to the frequency and this amounts to considerable in a long line.

2. There is greater difficulty in parallel operation of the high-frequency machines due to the fact that the armature reactions of the older types of high-frequency machines are high.

3. Machines for high frequencies are not so readily constructed for operation at slow speeds. This, however, will cease to be an objection with the increasing use of the steam turbine.

4. Not well adapted to the operation of rotary converters and single-phase series motors on account of added complications in construction and increased commutator troubles.

A frequency of 60 cycles is usually adopted if the power is to be used for lighting only, and 25 cycles are better for railway work alone. By the use of frequency changers the frequency of any system may be readily changed to suit the requirements of the service.

OVERHEAD LINES.

Having considered the calculation of the electrical constants of a transmission line and distributing system, we turn next to the mechanical features of the installation of the conductors and find two general methods of running the wires or cables.

In the first method the conductors are run overhead and supported by insulators attached to pins in cross-arms which, in turn, are fastened to the supporting poles. In the other methods the cables are placed underground and are supported and protected by some form of conduit.

Overhead construction is used when the lines are run through open country or in small towns. It forms a cheap method of providing satisfactory service and is reliable when carefully installed. It has the advantage that the wires may be placed some distance apart and, being air-insulated, the capacity of the line is much less than that of underground conductors.

The old practice in overhead line construction has always been to consider the design and erection of the line as work that anyone could do, it being taken as the simplest part of the electrical system. As a result, the line was a source of a great deal of trouble which was laid to almost any other cause than poor construction. The overhead line, when used, must be considered as a part of the power plant and it should receive as careful attention as any part of the central station or substation. It often has to meet much more severe conditions than the power plant itself and it is responsible to a very large extent for the reliability of service.

The new way of treating the question of overhead lines is to consider them as structures which must be designed to meet certain strains just as a bridge or similar structure is designed. This is especially true when steel or iron poles are used as is the case in nearly all transmission lines abroad.

The design of an overhead line may be divided into five parts:

1. **Location of line.**
2. **Supports for the line, pole, and cross-arms.**
3. **Insulators and pins.**
4. **Stresses sustained by the pole line.**
5. **Conductors, material, size.**

Some of these are purely mechanical features while others are both mechanical and electrical. Let us take them up in the order named.

Location of Line. The location of the line takes into account the territory over which the line must be run with respect to contour, direction, and freedom from obstructions as well as possible right of way. Width of streets, kind and height of buildings, liability to interference with or from other systems must be considered, when such are present. The right of way for electric lines may be secured, in some cases, along a railway or public road when its location is comparatively simple, provided it is not necessary to interfere with adjoining property. When adjoining property must be interfered with, or when the line is to run over sections containing no roads, it is usually possible to form contracts with the property owner such as shall free the line from future interference by the property owner. In general, the cost of such contracts will be comparatively low. Again, the right of way may be purchased outright as is preferable when right of way is being secured for high-speed electric railways. When the demands for right of way are in excess of a reasonable amount, the process of condemnation of property may be resorted to or the direction of the line may be changed so as to avoid such locations. A preliminary survey of the line should be made at the time the route is being located, such a survey consisting of the approximate location of the poles, notes of the changes in direction and level of the ground as well as of its character. This survey aids in the selection of material to be delivered to the different parts of the line. Changes in level are compensated for as much as possible by selecting long poles for the low places and short poles for the higher elevations, thus reducing the unbalanced strains in the line. The heavier poles should be used where there is a change in direction, where the line is especially exposed to the wind or where branch lines are taken off. It is sometimes necessary that power lines be run on the same poles as telephone wires, in which case the power conductors should, preferably, be located above the telephone wires.

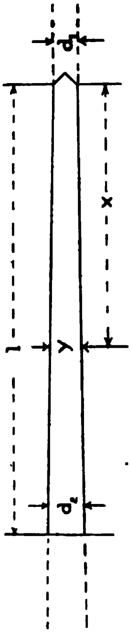


Fig. 31.

Supports, Poles. In this country, the support for aerial lines consists almost universally of wooden poles to which the cross-arms, bearing the insulator pins, are attached. These poles may be either natural grown or sawn. Abroad, the use of metal poles prevails. In order to determine the proper cross-section of a pole it may be regarded as a beam fixed at one end and loaded at the other, this load consisting of the weight of the wire, with attendant snow or sleet, which tends to produce compression in the pole, and the tension of the wires together with the effect of wind pressure, which tends to produce flexure. Only the latter stresses need be considered in selecting a pole for ordinary transmission lines. The poles are in the shape of a truncated cone or pyramid, the equation of which is:

$$y = d_1 + x\left(\frac{d_2 - d_1}{l}\right). \quad \text{See Fig. 31.}$$

y = diameter of any section.
x = distance from the top of the pole.
l = length of pole.

d_1 and d_2 = diameter of the pole at the top and bottom respectively.

The proper taper for a pole should be such that $d_2 = \frac{3}{2}$ of d_1. If $d_2 > \frac{3}{2}\, d_1$ the pole is heavier than need be as it would tend to break below the ground. If less than $\frac{3}{2}\, d_1$, the pole will tend to break above the ground and the material is not distributed to the best advantage.

In calculating the size of pole necessary to stand a certain stress, we have, from the principles of Mechanics,

$$M = \frac{S\,I}{\frac{d_2}{2}}$$

M = moment of resistance.

I = moment of inertia.

S = stress in the section at d_2 at which point the pole is least able to withstand the strain which comes on it.

M = Pl where P is the tension in the wires and l = length of pole in inches.

For a round pole, $I = \frac{\pi d^4_2}{64}$

and we have, $$Pl = \frac{\frac{S\pi d^4_2}{64}}{\frac{d_2}{2}} = \frac{S\pi d^3_2}{32}$$

Solving for S, $S = \frac{32\,Pl}{\pi d^3_2}$

For a sawn pole with square cross-sections the value of I is:

$$I = \frac{d^4_2}{12}$$

and $$Pl = \frac{S d^3_2}{6} \text{ or } S = \frac{6\,Pl}{d^3_2}$$

The value for S should not exceed a certain proportion of the ultimate strength of the material. If T represents the ultimate strength in pounds per square inch, then $P = \frac{T}{n}$ where n is known as the factor of safety and is ordinarily not taken less than 10 for wooden structures. A high factor of safety is necessary on account of the material not being uniform, and the uncertainty of the value of T.

Following are commonly accepted values of T:

Yellow pine	5,000 - 12,000 pounds
Chestnut	7,000 - 13,000 "
Cedar	11,500 "
Redwood	11,000 "

The value of $\frac{T}{n}$ should not be over about 800 for natural poles and 600 for sawn poles.

d_2 is measured at the ground line of the pole, not at the base.

Consider a pole of circular cross-section having a length of 35 feet and a diameter at the ground line of 12 inches. Using $\frac{T}{n} = 600$, what is the maximum allowable stress that should be applied at the end of the pole?

$$S = \frac{32\,Pl}{\pi d_2^3}$$

$$P = 600$$

$$l = 35 \times 12 = 420 \text{ inches.}$$

$$d_2 = 12$$

$$S = \frac{32 \times 600 \times 420}{3.1416 \times 1728} = 1{,}485 \text{ lbs.}$$

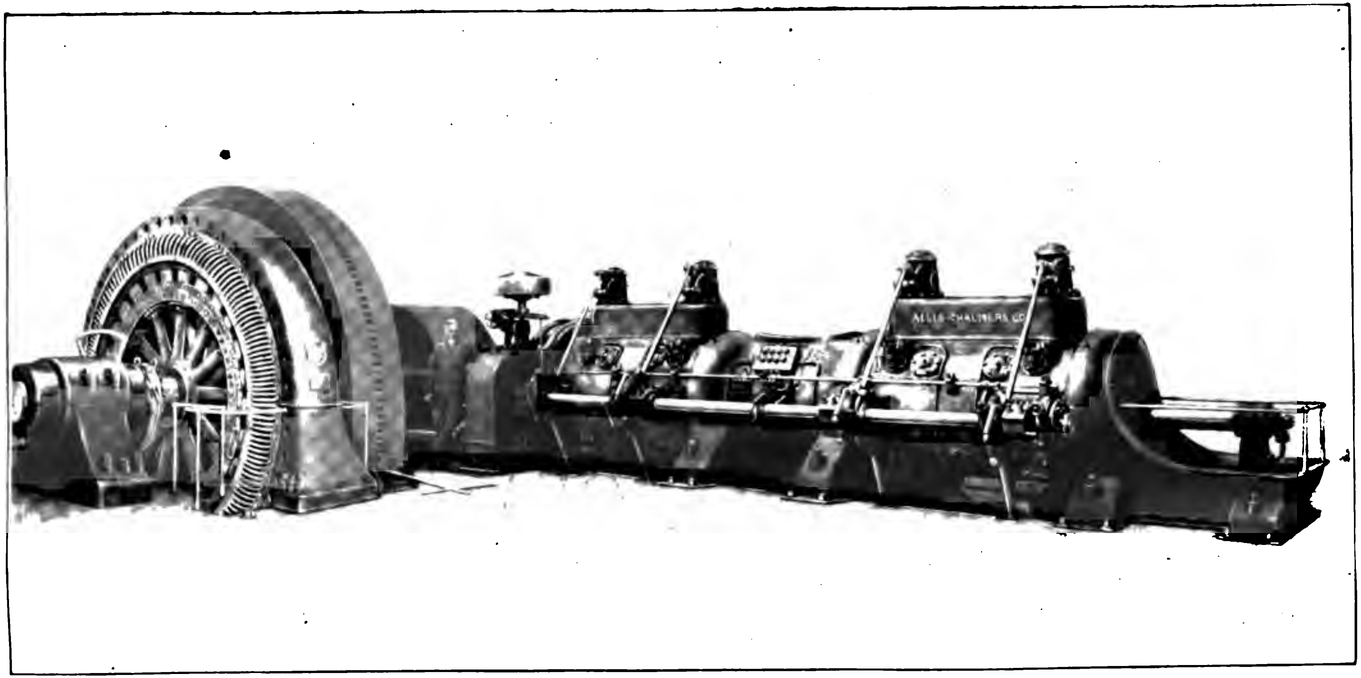
It is customary to select a general type of pole for the whole line determined from calculations based on the above formulæ, after the tension in the wire has been found, and not to apply such calculations to every section of the line. The line is then reinforced, where necessary, by means of guy wires or struts.

Following are some of the general requirements for poles:

Spacing should not exceed 40 to 45 yards.

Poles should be set at least five feet in the ground with an additional six inches for every five feet increase in length over thirty-five feet. Special care in setting is necessary when the ground is soft. End and corner poles should be braced and at least every tenth pole along the line should be guyed with ¼ or ⅜-inch stranded galvanized iron wire.

Regular inspection of poles, at least yearly, should be maintained and defective poles replaced. The condition of poles is best determined by examination at the base.



ALLIS-CHALMERS GAS ENGINE DIRECT-CONNECTED TO ALLIS-CHALMERS ALTERNATING-CURRENT GENERATOR

Poles should preferably be of good, sound chestnut, cedar, or redwood. Other kinds of wood are sometimes used, the material depending largely on the section of the country in which the line is to be erected and the timber available. Natural poles should be shaved, roofed, gained, and given one coat of paint before erecting.

Special methods of preserving poles have been introduced, chief among which may be considered the process of creosoting. Creosoting consists of treating the poles with live steam at a temperature of 225 to 250°, so as to thoroughly heat the timber, after which a vacuum is formed and then the containing cylinder is pumped full of the preserving material, a pressure of about 100 pounds per square inch being used to force the desired amount of material into the wood. The butts of poles are often treated with pitch or tar, but this should only be applied after the pole is thoroughly dry.

Guying of pole lines is one of the most important features of construction. Guys consist of three or more strands of wire, twisted together, fastened at or near the top of the pole, and carried to the ground in a direction opposite to that of the resulting strain on the pole line. The lower end is attached to some form of guy stub or guy anchor. This may be a tree, a neighboring pole, a short length of pole set in the ground, or a patent guy anchor. Guy stubs are set in the ground at an inclination such that the guy makes an angle of 90° with the stub or with the axis of the stub in the direction of guy, the stub in the latter case being held in place by timber or plate fastened at right angles to the bottom of the stub. Such a timber is known as a " dead man ".

The angle the guy wire makes with the pole should be at least 20°. When there is not room to carry the guy far enough away from the base of the pole to bring this angle to 20° or more, a strut may be used. This consists of a pole slightly shorter and lighter than the one to be reinforced. It is framed into the line pole near the top and set in the ground at a short distance from the base of the pole on the opposite side of the pole from that on which a guy would be fastened.

Stranded galvanized steel guy wire is used for guys. There are two general methods of attaching the guys to the top of the pole. In the one, a single guy is run, attached at or near the middle cross-arm, while in the other, known as "Y" guying, two wires are run to the top of the pole, one at the upper the other at the lower arm, and these united into a single line a short distance from the pole.

Head guying, guying in the direction of the line, is used when the line is changing level and for end poles. The guys are attached near the top of one pole and run to the bottom of the pole just above. Fig. 32 shows several methods of reinforcing pole lines. Special methods are adapted as necessary.

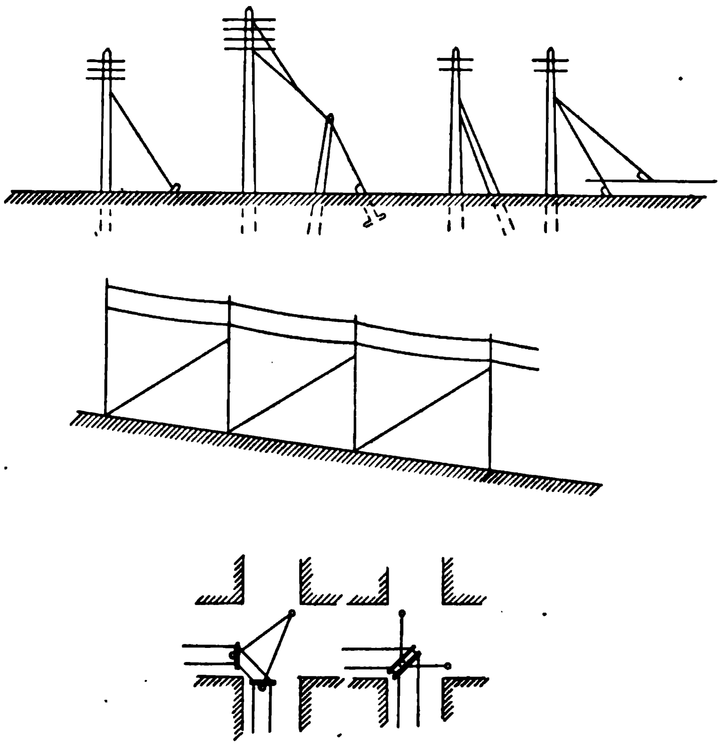


Fig. 32.

Cross-Arms. The best cross-arms are made of southern yellow pine. Oak is also used to a large extent. They should be of selected well-seasoned stock. The usual method of treatment is to paint them with white lead and oil. The size of cross-arms and spacing of pins have not been thoroughly standardized. For circuits up to 5,000 volts, $3\frac{1}{4} \times 4\frac{1}{4}$ or $3\frac{3}{4} \times 4\frac{1}{4}''$ cross-arms with spacing between pins of 16 inches, the pole pins being spaced 22 inches, are recommended. For higher voltages, special cross-arms and spacings are necessary. The cross-arms should be spaced at least 24 inches between centers, the top arm being placed 12 inches below the top of the pole. They are usually attached to the pole by means of two bolts and are braced by galvanized iron braces not less than $1\frac{1}{4} \times \frac{3}{16}$ inch and about 28 inches long.

Cross-arms are placed on alternate sides of the poles so as to prevent several of them from being pulled off should one become broken or detached. On corners or curves double arms are used In European practice, the cross-arm is done away with to a large extent, the wire being mounted on insulators attached to iron brackets mounted one above the other. Fig. 33 gives an idea of this construction.

Insulators. Electrical leakage between wires must be prevented in some way and various forms of insulators are depended upon for this purpose. The material used in the construction of these insulators should possess the following properties: high specific resistance; surface not readily destroyed and one on which moisture does not readily collect; mechanical strength to resist both strain and vibrating shocks. Its design must be such that the wire can be readily fastened to it and the tension of the wire will be transmitted to the pin without producing a strong strain in the insu-

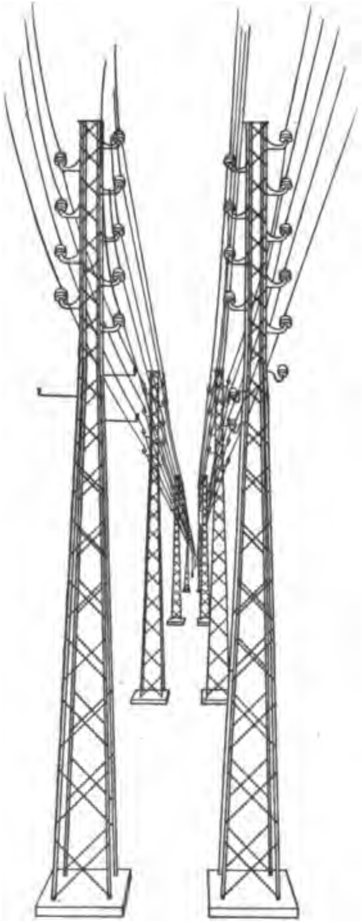
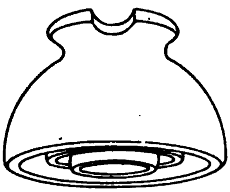
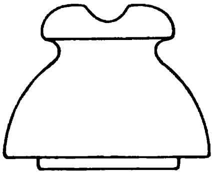


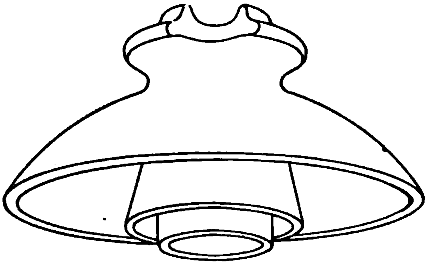
Fig. 33.



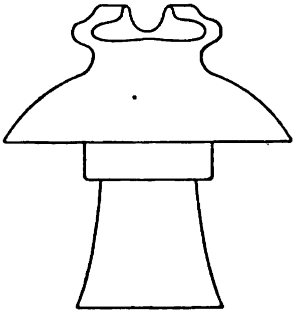
HEIGHT 3¾" TESTED AT 50,000V



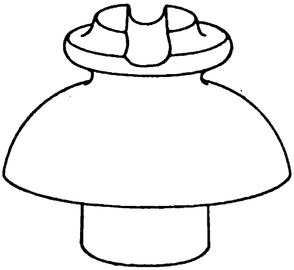
HEIGHT 3" TESTED AT 30,000V.



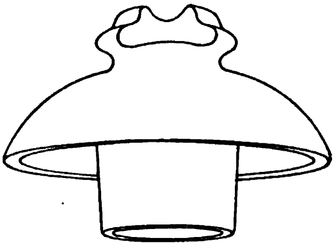
HEIGHT 4½" TESTED AT 70,000V.



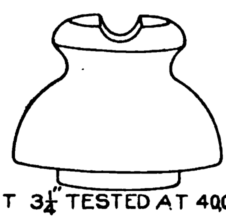
HEIGHT 7¼" TESTED AT 80,000V.



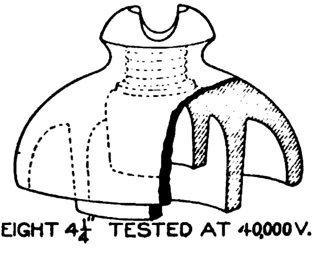
HEIGHT 4⅜" TESTED AT 50,000V.



HEIGHT 4¼" TESTED AT 50,000V.



HEIGHT 3¼" TESTED AT 40,000V.



HEIGHT 4¼" TESTED AT 40,000V.

Fig. 34.

lator. Leakage surface must be ample for the voltage of the line and so constructed that a large portion of it will be protected from moisture during rainstorms. The principal materials used are glass and porcelain.

Porcelain has the advantage over glass that it is less brittle and generally stronger and that it is less hygroscopic, that is, moisture does not so readily collect on and adhere to its surface. Glass is less conspicuous and is cheaper for the smaller insulators. Both materials are freely used for the construction of high-tension lines, while the use of glass prevails for the low-tension circuits.

All line insulators are of the petticoat type and are made up in various shapes and sizes. The larger size porcelain insulators are made up in two or more pieces which are fastened together by means of a paste formed of litharge and glycerine. The advantages of this form of construction are greater uniformity of structure, and each part may be tested separately. Fig. 34 shows several forms of insulators now in use with the voltage at which they are tested. The test applied to an insulator for high-tension lines should be at least double the voltage of the line, and some engineers recommend three times the normal voltage.

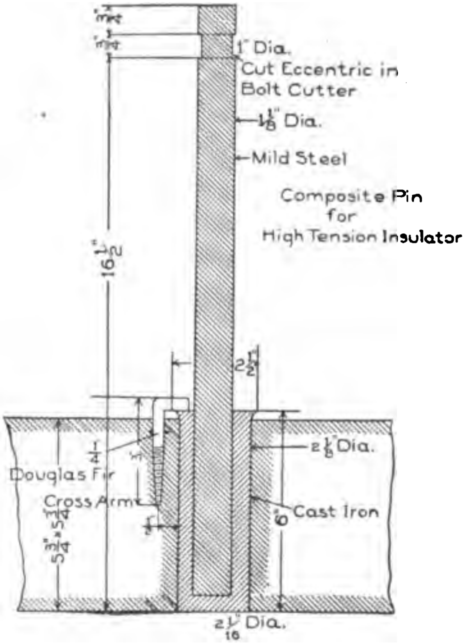


Fig. 35.

Pins. Pins made of locust wood boiled in linseed oil are preferred for voltages up to 5,000. Above this special pins are used. Wood pins are often objected to on account of the burning or charring which takes place in certain localities, and iron pins are being used to a large extent. Fig. 35 shows the dimensions of such a pin used on a 60,000-volt line. The insulator is fastened to the pin by means of a thread in a lead lug which is cast on top of the pin. The insulators in the construction shown in Fig. 33 are cemented to the iron brackets.

The Stresses sustained by the line may be classified as follows:

1. **Weight of wire, which includes insulation, and snow and sleet which may be supported by the wire.**
2. **Wind pressure upon the parts of the line.**

The strain produced by the weight of the wire on the pole itself need not be considered except in exceptional cases, because if the pole is sufficiently strong to withstand the bending strains, it is more than strong enough to withstand the compression due to the weight of the wires.

3. **Tension in the wire itself.**

Langley shows the pressure of the wind normal to flat surfaces to be equal to:

$$p = .0036\, v^2 = \frac{v^2}{280}.$$

p = pressure in pounds per sq. ft.
v = velocity in miles per hour.

For cylindrical surfaces the amount of pressure is $\frac{2}{3}$ that exerted on a flat surface of a width equal to the diameter of the cylinder. Without great error we may assume that the maximum wind pressure, and that for which calculation is necessary, is that at right-angles to the line, and a value of thirty pounds per square foot is sufficient allowance for exposed places, while twenty pounds per square foot is considered sufficient where the line is partially sheltered.

Example. What is the pressure, due to the wind, on the wires of a pole line containing three number 0000 wires, the poles being spaced 45 yards and the velocity of the wind such that the pressure may be taken as 30 pounds per square foot.

The diameter of a number 0000 wire is .460 inch. The area against which the wind exerts its force may be considered as:

$$\frac{2}{3} \times \frac{3 \times 45 \times 3 \times 12 \times .460}{144} = 5.166 \text{ square feet.}$$

$5.166 \times 30 = 155$ pounds pressure due to wind on wires.

The most important strain-producing factor in a line is that due to the tension in the wire itself. A wire suspended so as to hang freely between two supports assumes the form of curve known as a catenary, but for ordinary work the curve may be taken as a parabola the equation of which is simple and from which the following equations are derived:

$$D = \frac{H^2W}{8P_c}$$

$$P_c = \frac{H^2W}{8D}$$

$$L = H + \frac{8D^2}{3H}$$

When D = deflection or sag at lowest point in feet.
L = actual length of wire between supports in feet.
H = distance between supports in feet.
W = weight of wire in pounds per foot.
P_c = horizontal tension in the wire at the middle point.
$P_c = \frac{T}{n}$ where T = tensile strength of the wire and n = factor of safety. $n = 2$ to 6 under the conditions existing when the wire is erected. The temperature changes in the wire affect the value of this factor, it being greatest when the temperature is a maximum, and a minimum when the temperature is lowest, and calculation should be for the maximum strain that may come on the wires.

If L_t = length of a wire at a given temperature, t° C.
and L_{20} = length of a wire at a given temperature, 20° C.
Then, $L_t = L_{20}\,[1 + k\,(t - 20)]$.

k = .000012 for iron.
.0000108 to .0000114 for aluminum.
.0000172 for copper.

The following table gives the deflection of spans of wire in inches for different temperatures and different distances between poles, a maximum stress of 30,000 pounds per square inch being allowed at – 10° F, which gives a factor of safety of 2 for hard-drawn copper wire.

TABLE VII.

Temperature Effects in Spans.

Spans in Feet.	TEMPERATURE IN DEGREES FAHRENHEIT.								
	- 10°	30°	40°	50°	60°	70°	80°	90°	100°
	Deflection in Inches.								
50	.5	6	8	9	9	10	11	11	12
60	.7	8	10	11	11	12	13	13	14
70	1.	10	11	12	13	14	15	15	17
80	1.2	11	13	14	15	16	17	18	19
90	1.6	13	14	16	17	18	19	20	21
100	1.9	14	16	17	19	20	21	23	24
110	2.3	16	18	19	21	22	24	25	26
120	2.8	17	19	21	22	24	26	27	28
140	3.7	20	23	25	27	28	30	32	33
160	4.9	23	26	28	30	32	34	36	38
180	6.2	26	29	32	34	37	39	41	43
200	7.7	31	33	36	38	41	43	45	48

The above formulæ apply directly to lines in which the poles are the same distance apart and on the same level, and any number of spans may be adjusted at one time by applying the calculated stress at the end of the wire and the line will be in equilibrium; that is, there will be no strain on the poles in the direction of the wires. Special care must be taken to preserve this equilibrium when the length of span changes or when the level of the pole tops varies, and this is accomplished by keeping P_c and n constant for every span.

What is the tension in pounds per square inch at the center of a span of number 0000 wire when the poles are 120 feet apart and the sag is 16 inches?

$$P_c = \frac{H^2 W}{8D}$$

$$H = 120$$

$$D = \frac{16}{12} = 1\tfrac{1}{3} \text{ feet.}$$

$$W = .64 \text{ pounds.}$$

$$P_c = \frac{(120)^2 \times .64}{8 \times 1\frac{1}{3}} = 864 \text{ pounds}$$

The cross-section of number 0000 wire is,—

$$\pi \times (.23)^2 = .1662 \text{ square inches.}$$

$$864 \div .1662 = 5200 \text{ pounds per square inch.}$$

The regulation of the system and the amount of power lost in transmission together determine the cross-section of the conductors to be used. The amount of power lost, for most economical operation can be determined from the cost of generating power and the fixed charges on the line investment. Either copper or aluminum wire or cables may be used. The latter is lighter in weight but more care must be taken in erecting and it is more difficult to make joints.

UNDERGROUND CONSTRUCTION.

In large cities or other localities where, if overhead construction be used, the number of conductors becomes so great as to be objectionable, not alone on account of appearance but also on account of complication and danger, the lines are run underground. The expense of installing underground systems is very great compared with that of overhead construction, but the cost of maintenance is much less and the liability to interruption of service, due to line troubles, greatly reduced. The essential elements of an underground system are the conductor, the insulator, and the protection. The conductor is invariably of copper, the insulator may be rubber, paper, some insulating compound, or individual insulators, depending on the system, while the protection takes one of several forms. The system, as a whole, may be divided into

Solid or built-in systems.
Trench systems.
Drawing-in systems.

As an example of the first, we have the *Edison Tube system*, which is especially adapted to house-to-house distribution and is used to a large extent for direct-current three-wire distribution in congested districts. It is made up of copper rods as conductors (three of equal size for mains and the neutral but ½ the size of the main conductors in feeders), which are insulated from each other by an asphaltum compound. This compound also serves as an insulation from the protecting case, which consists of wrought-iron pipe. Pilot wires are also often installed in the feeder tubes. This tube is built up in sections about twenty feet long. In insulating the conductors, they are first loosely wrapped with jute rope so as to keep them from making contact with each other,

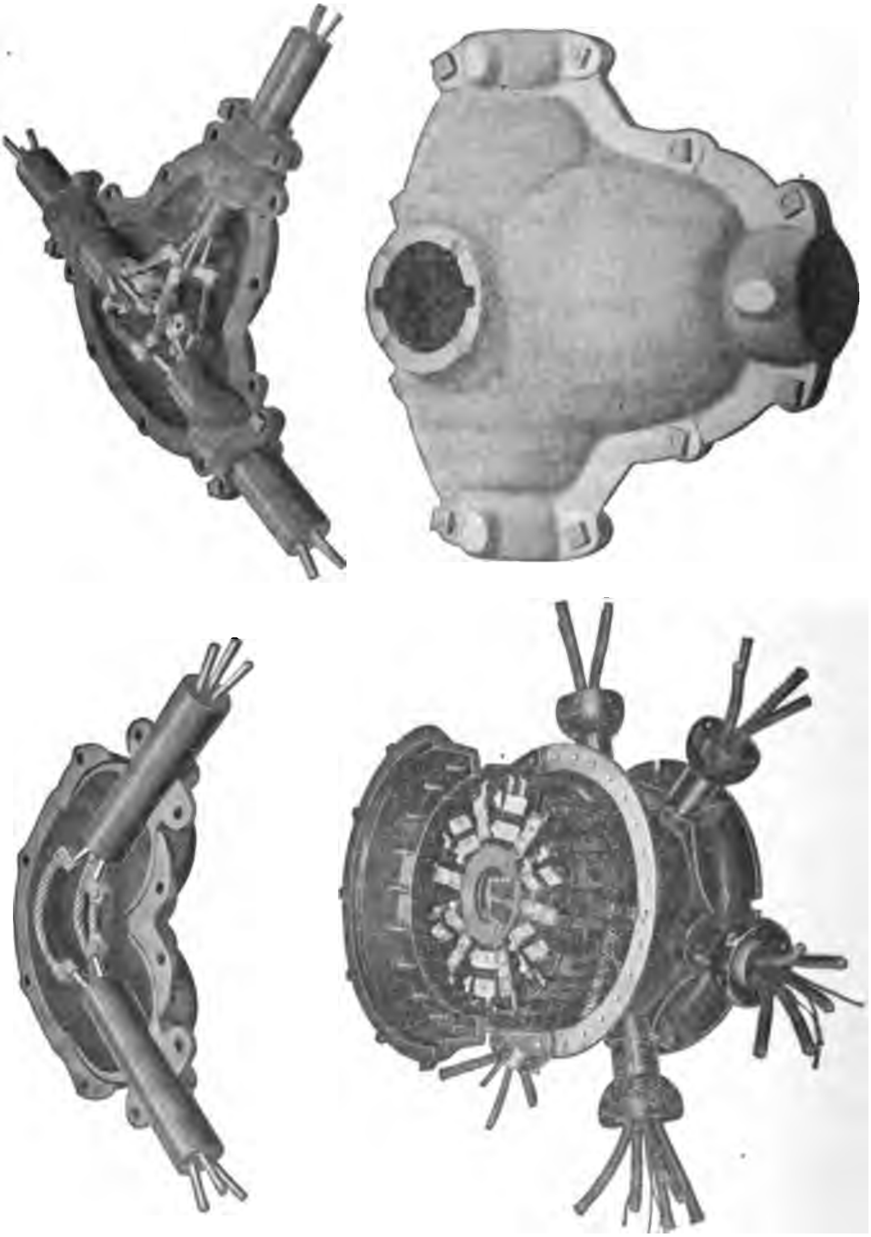


Fig. 36.

and with the pipes, and the heated asphaltum forced into the tube from the bottom, when the tube is in a vertical position. The ends of the conductors and the tubes must be joined and properly insulated in a completed system. Special connectors are furnished for the conductors, and cast-iron coupling boxes are fitted to the ends of the tube as shown in Fig. 36. After the conductors are properly connected, the cap is put on this coupling box and the inside space then filled with insulating compound through a hole in the cap. This hole is later fitted with a plug to render the box air-tight. The system is a cheap one, though the joints are expensive. It is not adapted to high potentials.

The *Siemens-Halske* system of iron-taped cables consists of insulated cables encased in lead to keep out moisture, this lead sheathing being in turn wrapped with jute which forms a bedding for the iron tape. The iron tape is further protected by a wrapping thoroughly saturated with asphaltum compound. These cables may be made up in lengths of from 500 to 600 feet.

In unexposed places, such as across private lands, the steel taping may be omitted and the lead sheathing simply protected by a braid or wrapping saturated with asphaltum.

The *Trench* system consists of bare or insulated conductors supported on special forms of insulators as in overhead construction, the whole being installed in small closed trenches. As this system is not used to any extent in America, but one system, the Crompton system, will be described.

In the Crompton system, bare copper strips are used, each 1 to 1½ inches wide and ¼ to ½ inch thick. These strips rest in notches on the top of porcelain or glass insulators, supported by oak timbers embedded in the sides of the cement-lined trench. This trench is covered with a layer of flagstone. These insulators are spaced about 50 feet and about every 300 feet a straining device is installed for taking up the sag in the conductors. Handholes are located over each insulator.

There are several of the *drawing-in* systems, and certain of these have come to be considered standard underground construction in the United States. It is no longer deemed advisable to construct ducts which will serve as insulators, but they are de-

369

pended on for mechanical protection only, and should fulfill the following requirements:

They must have a smooth interior, free from projections, so that the cables may be readily drawn in and out.

They must be reasonably water-tight.

They must be strong enough to resist injury due to street traffic and accidental interference from workmen.

Among the materials used for duct construction may be mentioned: iron or steel, wood, cement, and terra cotta. *Wood* is used in the form of a trough or box, or in the form of wooden

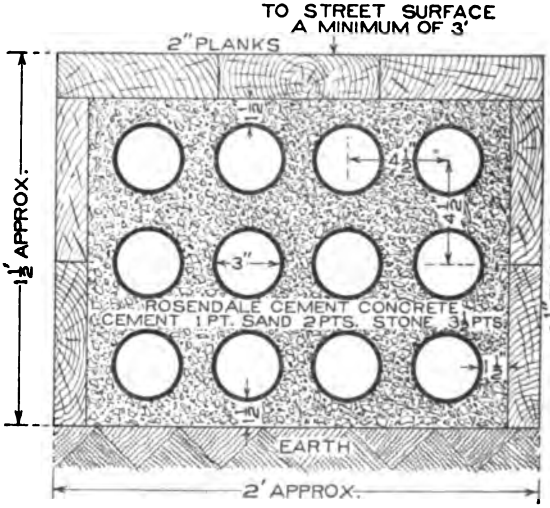


Fig. 37.

pipes. The latter is known as "pump log" conduit. The wood used for this purpose must be very carefully seasoned and then treated with some antiseptic compound, such as creosote, in order for the duct to give satisfactory service. If improperly treated, acetic acid is formed during the decay of the wood, and this attacks the lead covering of the cable, destroying it and allowing moisture to deteriorate the insulation. Wood offers very little resistance to the drawing in of the cables, and it is a cheap form of conduit, though it cannot be depended on for long life.

One of the best and at the same time most expensive systems is the one using *wrought-iron pipes*, laid in a bed of concrete. The ordinary construction of the duct consists of digging a trench of the desired size and covering the bottom, after it is carefully graded, with a layer of good concrete from two to four inches thick. Such a cement may consist of Rosendale cement, sand, and broken stone in the ratio of 2, 3, 5, the broken stone to pass through a sieve of 1½-inch mesh. The sides of the trench are lined with 1½-inch planks. The first layer of pipes consisting of wrought-iron pipes 3 to 4 inches in diameter, 20 feet long, and ¼ inch thick, joined by means of water-tight couplings, is laid on this concrete, and the space around and above them filled with concrete. A second layer of pipes is laid over this, and so on. A covering of concrete 2 to 3 inches thick is placed over the last layer, and a layer of 2-inch plank is placed over all, to protect against injury by workmen. Fig. 37 shows a cross-section of such duct construction. The pipe should be reamed so as to remove any internal burs which might injure the insulation during the process of drawing in.

A modification of this system consists of the use of *cement-lined wrought-iron pipes*. This usually consists of eight-foot lengths made of riveted sheet-iron pipes. Rosendale cement is used for the lining, this lining being about ⅝ inch thick. The external diameter of the pipe is about 4½ inches. The outside of the pipe is coated with tar to prevent rusting. The sections have a very smooth interior and are light enough to be easily handled. They are embedded in concrete, similar to the system previously described. Connections between the sections are made by means of joints, constructed on the ball-and-socket principle, moulded in the cement at the ends of the sections. This forms a cheaper construction than the use of full-weight pipe.

Earthenware Conduits. This form of conduit is being extensively used for underground cables. The sections may be of the single-duct or multiple-duct type. The former consists of an earthenware pipe from 18 to 24 inches in length. The internal diameter is from 2½ to 3 inches. These are laid on a bed of concrete, the separate tiles being laid up in concrete in such a manner as to break joints between the various ducts. In the multiple-duct system the joints are wrapped with burlap and the whole embedded in concrete. This form of conduit has a smooth interior and the cables are readily drawn in and out. The single-duct type lends itself admirably to slight changes of direction that may be necessary. Fig. 38 shows both forms of duct, while Fig. 39 shows a cement-lined iron-pipe duct system, laid in concrete, in course of construction.

Other forms of conduits are ducts formed in concrete, earthenware troughs, cast-iron troughs, and fibre tubes.

Manholes. For all drawing-in systems, it is necessary to provide some means of making connections between the several lengths of cable after they are drawn in, as well as for attaching feeders. Since the cables cannot be handled in lengths greater than about 500 feet, and less than this in many cases, vaults or junction boxes must be placed at frequent intervals. Such vaults are known as splicing vaults or manholes. The size of the manhole depends upon the number of ducts in the system, as well as on the depth of the conduit. If the ducts be laid but a short distance from the surface of the street and traffic is light, the cables may be readily spliced with a manhole but 4 feet square and 4 feet deep. The smaller vaults are often called "*hand-holes*". Deeper vaults are from 5 to 6 feet square, and the floor should be at least 18 inches below the lowest ducts on account of convenience to the workmen and to serve as collecting basins for water which gets into the system. The ducts should always be laid with a gentle slope toward such manholes.

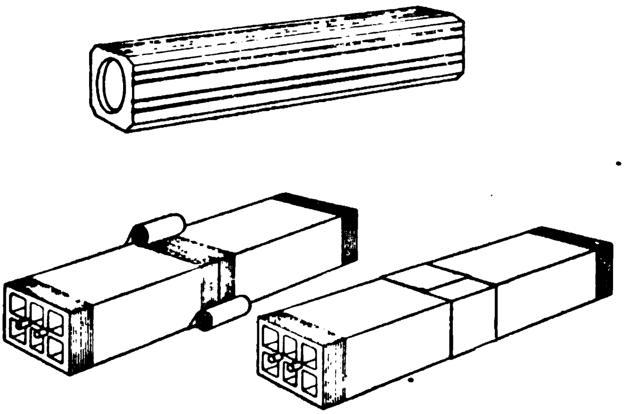


Fig 38.

Common construction consists of a brick wall laid upon a concrete floor, the brick being laid in cement and being coated internally with cement. The cables follow the sides of the manhole and they are supported on hooks set in the brickwork. This causes quite a waste of cable in large manholes. Care should be taken that workmen do not use the cables, so supported, as ladders in entering and leaving the manhole, as the lead sheathing may be readily injured when the cables are so used.

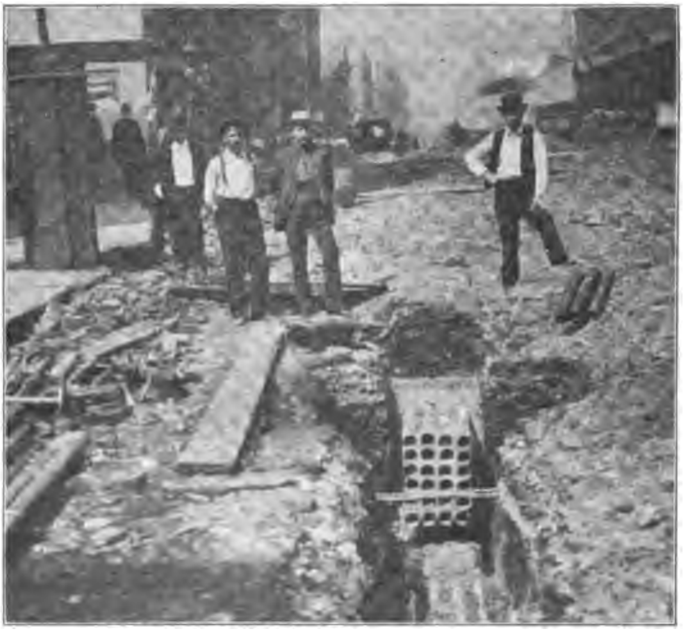


Fig. 39.

Conductors are drawn into place by the aid of some form of windlass. Special jointed rods, 3 to 4 feet long, may be used for making the first connection between manholes or a steel wire or tape may be pushed through. A rope is drawn into the duct and the cable is attached to this rope. Fig. 40 shows one way in which the cable may be attached to the rope. Care must be taken to see that no sharp bends are made in the cable during this process. Cable should not be drawn in during extremely cold weather unless some means are employed for keeping it warm, owing to the liability of the insulation to be injured by cracking.

Conduit systems must be ventilated in order to prevent explosion due to the collecting of explosive mixtures of gas. Many special ventilating schemes have been tried, but the majority of systems depend for their ventilation on holes in the manhole covers. This prevents excessive amounts of gas from collecting but does not always free the system from gas so completely as to make it safe for workmen to enter the splicing vault until the impure air has been pumped out.

The above applies to the main conduit system. Auxiliary ducts are laid over the main ducts and distribution accomplished from hand-holes in this system.

It is customary to ground the lead sheaths of the cables at frequent intervals, thus in no way depending on the ducts even when made of insulating material, for insulation.

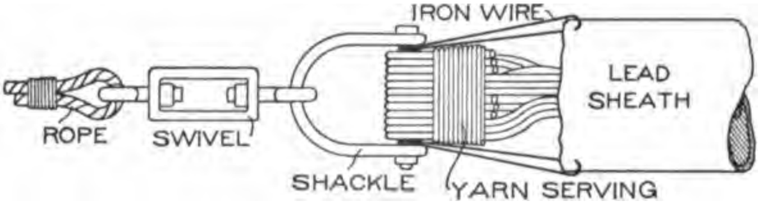
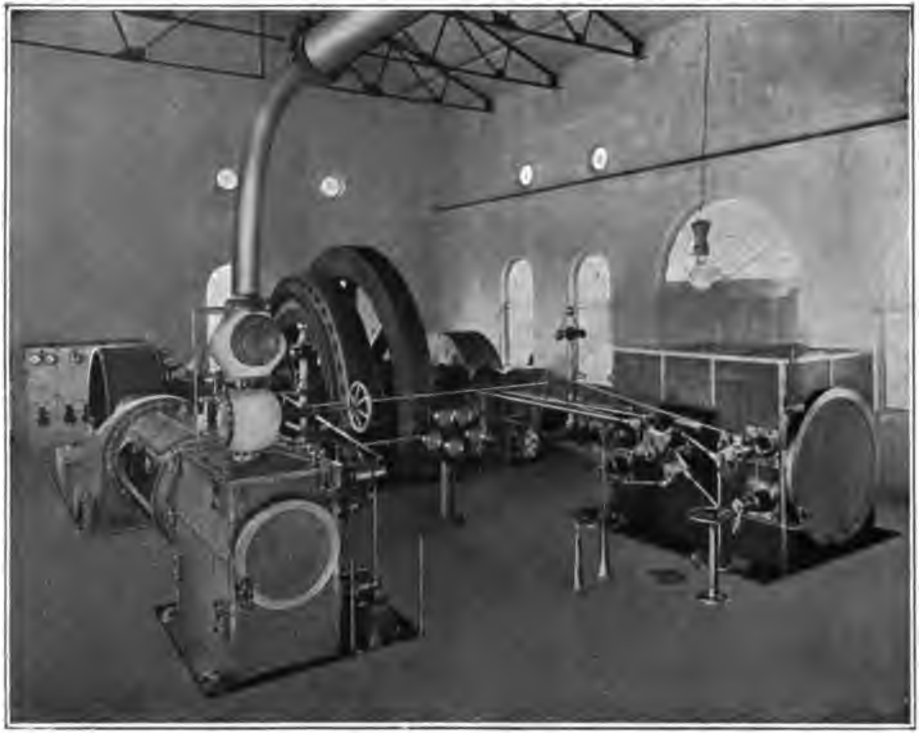


Fig. 40.

Cables. Well insulated copper cables are used for underground systems. On account of the fact that various materials, such as acids and oils which are injurious to the insulation, come in contact with the cable, it is necessary that it be protected in some manner. A lead sheath is employed for this purpose. This sheath is made continuous for the whole length of the conductor, and with its use it is possible to employ insulating materials such as paper which, on account of being readily saturated by moisture, could not be used at all without such a hermetically sealed sheath. Lead containing a small percentage of tin is usually employed for this purpose. The sheath may consist of a lead pipe into which the cable is drawn, after which the whole is drawn through suitable dies, bringing the lead in close contact with the insulation or the casing may be formed by means of a hydraulic press.

Yarns thoroughly dried and then saturated with such materials as paraffin, asphaltum, rosin, etc., paper, both dry and saturated,



1,500 K. W. ENGINE-TYPE A. C. GENERATOR, THREE-PHASE, 2,200 VOLTS, 60 CYCLE, 82 R. P. M.—HIGHLAND PARK MFG. CO.

Westinghouse Electric & Mfg. Co.

and rubber are the materials more generally employed for insulation. When paper is employed, it is wound on in strips, the cable being passed through a die after each layer is applied, after which it is dried at a temperature of 200° F to expel moisture. After being immersed in a bath of the saturating compound it is taken to the hydraulic presses where the lead sheath is put on.

When rubber insulation is used, the conductors are tinned to prevent the action of any uncombined sulphur which may be present in the vulcanized rubber. The Hooper process consists of using a layer of pure rubber next to the conductors and using the vulcanized rubber outside of this. One or two layers of pure rubber tape are put on spirally, the spiral being reversed for each layer. Rubber compound in two or more layers is applied over this in the form of two strips which pass between rollers which fold these strips around the core and press the edges together. Prepared rubber tape is applied over this, after which the insulator is vulcanized and the cable tested. If satisfactory the external protection is applied.

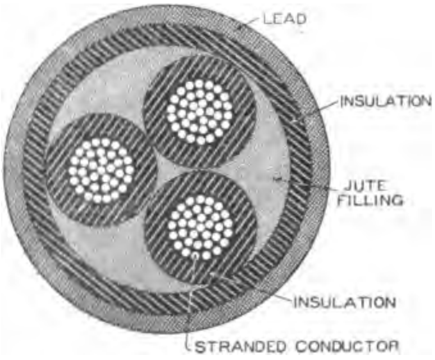


Fig. 41.

Cable for polyphase work is made up of three conductors in one sheath. Fig. 41 shows a cross-section of cable manufactured for three-phase transmission at 6,600 volts. The conductors of this cable have a cross-section equivalent to a number 0000 wire, to which an insulation of rubber $\frac{6}{32}$-inch thick is applied. These three conductors are twisted together with a lay of about 20 inches. Jute is used as a filler, and a second layer of rubber insulation $\frac{4}{32}$-inch thick is then applied. The lead sheath employed is $\frac{1}{8}$-inch thick, and is alloyed with 3% of tin.

Joints in cables must be carefully made. Well-trained men only should be employed. The insulation applied to the joint should be equivalent to the insulation of the cable at other points, and the joint as a whole must be protected by a lead sheath made continuous with the main covering by means of plumbers' joints.

Some engineers prefer rubber, some paper insulation, but both types are giving good service, and are used up to voltages of 22,000. It is customary to subject each cable to twice its normal potential soon after it is installed. This voltage should not be applied or removed too suddenly as unnecessary strains might be produced in this manner.

Rubber-insulated cables should never be allowed to reach a temperature exceeding 65° to 70° C (149° to 158° F). Paper will stand a temperature of 90° C (194° F), but it is neither desirable nor economical to allow such a temperature to be reached. The following table is of interest in connection with underground cables. The dimensions here given are only general.

TABLE VIII.

Typical Cable Construction.

Cables.	No. of Conductors.	Character of Conductor	Sizes of Individual Wires.
Electric light less than 500 volts..	Single	Stranded	No. 10 B.&S. or smaller.
Arc lighting....................	Single	Solid	No. 6 or 4 B.&S.
High-tension power transmission.	Single, concentric, duplex, or three conductors	Stranded	No. 10 B.&S. or smaller.

Thickness of Insulation.

	Rubber.	Saturated Fiber.	Saturated Paper.	Dry Paper.	Thickness of Lead.
	Inch.	Inch.	Inch.	Inch.	Inch.
Electric light less than 500 volts..................	$\frac{3}{32}$	$\frac{6}{32}$	$\frac{5}{32}$	$\frac{5}{32}$	$\frac{1}{16}$ to $\frac{1}{10}$
Arc lighting...............	$\frac{5}{32}$ to $\frac{8}{32}$	$\frac{8}{32}$	$\frac{8}{32}$	$\frac{8}{32}$	$\frac{1}{10}$
High-tension power transmission.................	$\frac{5}{32}$ to $\frac{8}{32}$	$\frac{8}{32}$	$\frac{8}{32}$	$\frac{8}{32}$	$\frac{1}{10}$

Selection of Voltage to be Used. The voltage to be selected for a given system depends on the distance the power is to be transmitted as well as its amount, and on the use to be made of the power. If a lighting load is concentrated in a small district, a 220-volt three-wire system will give very good service. If the region is a little more extended, possibly a 440-volt three-wire system using 220-volt lamps would serve the purpose without an excessive loss of power or a prohibitive outlay for copper. For location when the service is scattered, a distribution at from 2,200 to 4,000 volts alternating current is used, transformers being located as required for stepping down the voltage for the units which may be fed from a two- or three-wire secondary system.

2,300 volts (alternating) is a standard voltage for lighting purposes and for polyphase systems; 2,300 volts is often taken as the voltage between the outside wires and the neutral wire of a four-wire three-phase distribution.

For railway work, 550 to 600 volts direct current is used up to distances of about 5 or 6 miles, beyond which it becomes more economical to install an alternating-current main station and supply the line at intervals from substations to which the power is transmitted at voltages of from 6,600 to 30,000 or even higher, depending on the distance it is to be transmitted. At present, the highest voltage used in long-distance transmission is 60,000, though higher values are contemplated. Such voltages are used only on very long lines, and each one becomes a special problem. It is always well to select a voltage for apparatus which may be considered as standard by manufacturing companies, as standard apparatus may always be purchased more cheaply and furnished in shorter time than special machinery.

Protection of Circuits. Lightning arresters are installed at intervals along overhead lines for the protection of connected apparatus. For ordinary lighting circuits, such arresters are installed for the protection of transformers, and are located preferably on the first pole away from the one on which the transformer is installed. Care should be taken to see that there are no sharp bends or turns in the ground wire and that there is a good ground connection. For the high-tension lines, lightning arresters at either end of the circuit are relied on to afford the greater part of the protection. In some localities, a wire strung on the same pole line at a short distance from the power wires and grounded at very frequent intervals has been found to reduce troubles due to lightning.

The grounding of the neutral of three-wire secondary systems forms a means of protection of such circuits against high potentials which might arise from accidental contact with the primaries, and is recommended in some cases. The grounding of the neutral of high-tension systems reduces the potential between the lines and the ground, but a single ground will cause a short-circuit on the line with any grounded system. Grounding, through a resistance which will limit the flow of current in such a short-circuit, has been recommended and is employed in some instances. Spark arresters are installed at the ends of high-tension underground systems to prevent high voltages which might injure the insulation in case of sudden changes in load, grounds, and short-circuits.

REVIEW QUESTIONS.

PRACTICAL TEST QUESTIONS.

In the foregoing sections of this Cyclopedia numerous illustrative examples are worked out in detail in order to show the application of the various methods and principles. Accompanying these are examples for practice which will aid the reader in fixing the principles in mind.

In the following pages are given a large number of test questions and problems which afford a valuable means of testing the reader's knowledge of the subjects treated. They will be found excellent practice for those preparing for Civil Service Examinations. In some cases numerical answers are given as a further aid in this work.

REVIEW QUESTIONS

ON THE SUBJECT OF

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

PART I.

1. Why is the steam turbine well adapted for direct connection?

2. On a three-wire system is it better to use 110-volt or 220-volt motors? Explain why.

3. Describe construction and operation of the Fort Wayne self-starting synchronous motor.

4. What methods are used for controlling the speed of induction motors? Which one is preferable?

5. How can the friction of brushes and bearings be tested roughly?

6. What points should be considered in the selection of a machine?

7. Give a sketch of the connections of a compound-wound motor.

8. What is the advantage of a synchronous motor when its field is over excited? Explain.

9. Give a safe rule to follow for personal protection when handling electrical circuits of a sufficiently high voltage to be dangerous.

10. What precautions must be taken in fixing a direct-connected set?

11. Why should starting boxes always be furnished with direct-current motors?

12. (a) How are small induction motors started? (b) Why cannot large sizes be started in the same way?

13. If a machine is to be taken apart for the purpose of cleaning or inspecting it, what precautions should be taken?

14. Describe the method of lacing a belt.

15. How are dynamotors and motor-generator sets started?

16. What precaution should be taken when starting a new machine for the first time.

17. Immediately after stopping a machine what should be done to it?

18. What advantages have circuit breakers over fuses?

19. What are the advantages of the single-phase series motor for electric railway work?

20. What is an inclosed fuse, and in what way is it better than a link fuse?

21. Why is it well to put the brushes of a generator in contact with the commutator before starting?

22. Explain the principle and use of a starting compensator.

23. What advantage does rope driving possess over ordinary belting?

24. When synchronizing two alternators should the switch be closed when the two machines are approaching synchronism, or when they are receding from it.

25. How can sparking at the commutator be measured roughly?

26. In placing a knife switch should it be so located that gravity tends to open it or to close it?

27. Describe with sketch the connections for two compound-wound dynamos in parallel.

28. How would you test a machine for balance?

29. Describe with sketch the connections for a typical single-phase installation.

30. What points must be considered if two alternators are to be run in parallel?

31. Describe with sketch the method of synchronizing on a three-phase system.

32. Should the loose side of a belt be on the top or below? Explain why.

33. Give a sketch of two generators connected on the three-wire system.

34. Why is a series motor particularly adapted for railway work?

REVIEW QUESTIONS

ON THE SUBJECT OF

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

PART II.

1. In measuring resistance with the Wheatstone bridge, what is the objection of using a ratio of 1000 : 1 or 100 : 1?

2. Describe a tachometer. What advantage has this over the speed counter?

3. What is the torque of a 20 horse-power motor running at the rate of 600 r.p.m.?

4. When the armature of a machine becomes overheated and the belt is tight on the tension side, to what would you ascribe the cause and how would you remedy it?

5. Explain how to true up the commutator in case it becomes rough or uneven.

6. Describe a method of testing to see if the armature is centered between the pole pieces.

7. What is the pull in pounds in the case of a 40 horse-power motor if the speed is 550 r.p.m. and the pulley is 3 feet in diameter?

8. What do you understand to be meant by a ground in the armature?

9. If the speed of a generator is too high, what effect does this have on the voltage?

10. Describe with formula the direct-deflection method of measuring insulation resistance.

11. Describe a method of determining the current in a circuit if you have a voltmeter but no ammeter at hand.

12. How does eddy-current loss vary with the speed?

13. Explain briefly the method of separating the eddy current loss from the hysteresis loss in a generator.

14. How does an eccentric commutator manifest itself?

15. If the residual magnetism of a dynamo be weak or entirely destroyed, how would you explain the cause for the same? How would such trouble manifest itself, and what is the remedy?

16. What resistance does a Weston voltmeter usually have?

17. Supposing the commutator of a machine is covered with a dark coating, while the commutator brushes and brush holders show marks of abnormal heat, what is likely to be the cause and what remedy should be applied?

18. Name the causes of the voltage of a generator being too low.

19. What difficulty would arise in attempting to measure the armature resistance of a 20 horse-power 110-volt shunt machine with the Wheatstone bridge?

20. In testing the output of a large generator, how would you dispose of the large current generated? Give two methods.

21. What is meant by the efficiency of a generator?

22. Which is preferable to use on a commutator, sandpaper or emery?

23. Which is preferable, that the commutator should have a bright, clean appearance, or be covered with a brown glaze or polish?

24. How can Foucault currents in the pole-pieces or field-cores be detected? What usually gives rise to such action?

25. What is the advantage of over-compounding so that a machine gives a higher voltage at full load than at low load?

26. A motor which is running without load is found to take excessive current; give a cause and remedy for the same.

27. If the field coils of the machine are too hot as determined by testing with the hand, what remedy would you apply?

28. Why cannot insulation resistance be measured by means of the Wheatstone bridge?

29. How could you determine the speed of a belted machine without the use of any sort of a speed indicator?

30. What is meant by the efficiency of a motor?

31. How does hysteretic loss vary with the speed?

REVIEW QUESTIONS

ON THE SUBJECT OF

POWER STATIONS.

1. Why is it desirable to allow a reserve capacity when deciding upon the number of units to be installed ?

2. Draw a diagram of the piping system for what you consider a first-class arrangement of the units.

3. Would you use a high or low-speed engine (*a*) in the case of a 200 K.W. generator; (*b*) in the case of a 300 K.W. generator; (*c*) in the case of a 1,000 K.W. generator?

4. When alternators are driven in parallel by gas engines, what arrangement is used to compensate for the variation in angular velocity ?

5. Is it better to have a machine of very high efficiency at the expense of excessive cost, or to have it reasonable in price with lower efficiency ?

6. What arrangement is now frequently used to avoid placing the different pieces of apparatus directly on the panels of a switchboard ?

7. Explain the function of a substation and tell of what its equipment should consist.

8. What are the advantages of oil switches ?

9. Explain why the capacity of a 6-phase rotary converter is greater than that of a single-phase, two-phase, or three-phase.

10. Which system of charging for power do you consider the fairest and best ? Explain why.

11. Explain what is meant by a reverse-current relay, and give an example of its usefulness.

12. What factors must be taken into consideration when locating a rotary converter substation ?

13. Discuss the requirements of boilers for central station operation.

14. What are the advantages and disadvantages of mechanical draft over natural draft?

15. Do you believe the gas engine will ever replace the steam engine as a prime mover? Give reasons.

16. Should an exciter be direct-connected to the shaft of an alternator or should it be belt-connected, and why?

17. How does the lightning arrester for alternating-current work differ from that for direct-current work?

18. If a dynamo is located immediately above the engine, show by sketch how you would arrange the belting.

19. Which type of circuit breaker do you consider better, the carbon break or the magnetic blow-out type?

20. Why is it desirable to keep careful station records and of what should such records consist?

21. In direct-current railway work what is the maximum distance over which power may be economically transmitted?

22. Draw a diagram of a system of piping in which provision may be easily made to allow for expansion of pipes, while on the other hand a damaged section may disable one boiler or one engine.

23. Describe the Curtis turbine and explain the method of governing the same.

24. What points should be taken into consideration when deciding upon the voltage to use for a given system?

25. Do you consider Niagara Falls a good location for the large power plants located there? Explain fully your reason for answer.

26. Upon what does the ratio of the voltage applied to the alternating-current side and that applied to the direct-current side of a rotary converter, depend?

27. In charging for power, why should a higher rate be demanded for that which is used during the peak hours?

28. In the case of a large lighting station, why is it desirable that there should also be a demand for power?

29. What are the advantages of cross connecting in the ring system of piping over the same system without cross connecting?

REVIEW QUESTIONS

ON THE SUBJECT OF

STORAGE BATTERIES.

1. What is the lowest voltage to which a lead battery should be discharged?

2. What means may be employed to make up for the drop in potential of storage batteries during discharge?

3. What causes sulphating?

4. What plate of a storage battery is the positive?

5. Describe the several indications by which the amount of charge in a storage battery can be determined.

6. How is the capacity of a storage battery usually expressed?

7. What is an electrolyte?

8. What is meant by a floating battery, and when is it applicable?

9. How must a storage battery room be arranged?

10. What causes buckling?

11. Why are there always more negative plates than positive plates in a storage battery?

12. Give several applications of storage batteries.

13. When a storage battery is charged, what is found on the positive plate? What is found on the negative plate? What occurs when the cell is discharged?

14. What is the maximum voltage obtainable from a lead storage cell?

15. How may sulphating and buckling be prevented?

16. How would you put a battery out of commission for a long period, and how would you place it in service again?

17. What is the difference in construction between Faure and Planté plates?

18. What is the essential difference between a primary and a storage battery?

19. What instruments are required on a storage battery switchboard, and how are they connected?

20. If a battery be discharged at a greater rate than its normal, how does it temporarily affect the capacity of the cell?

21. What impurities in the electrolyte must be guarded against? How is their presence caused, and how determined?

22. Which type of cell has the larger storage capacity per lb. of cell, the Faure or the Planté? Why?

23. Why is the storage battery useful in electrical laboratories?

24. What is the specific gravity of the electrolyte of a lead cell when fully charged, and about what when discharged?

25. What is the constant-current booster system, and where is it most applicable?

REVIEW QUESTIONS

ON THE SUBJECT OF

POWER TRANSMISSION.

---

1. Of the various arrangements for obtaining the three-wire system, shown in Fig. 12, which is the one most commonly used in practice?

2. What is the drop in voltage and the loss in energy in a line 5 miles long composed of No. 6 wire, if the current flowing is 6.8 amperes?

3. What is the purpose of transposing wires? Explain the principles upon which transposition is based.

4. What materials are commonly used for conductors for electrical transmission of power?

5. What is the disadvantage of using the bridge arrangement for obtaining a three-wire system from a single generator?

6. Give the formula for calculating the area of conductor in circular mils of an alternating current transmission line, explaining the meaning of the symbols used.

7. What relation must exist between the capacity and self-induction of a line in order that the one may neutralize the other?

8. What is the area in square mils of a No. 3 wire?

9. Outline the method of determining the most economical feeding point for a system.

10. What limit determines the allowable rise in temperature in a conductor carrying current?

11. Show a sketch of the connections of the three-phase four-wire system.

12. Supposing a circuit has a capacity of .6 micro-farads, the frequency of the circuit being 25 cycles; what must be the inductance to exactly neutralize its capacity?

13. Without referring to the book, show a sketch of the anti-parallel system of feeding with tapering conductors.

14. For what purpose is aluminum used principally, and why?

15. To what sort of distribution is the series multiple system applicable?

16. Under what conditions is it more economical to use polyphase systems than single-phase?

17. Give approximate values of power factor for incandescent lights alone and also for induction motors alone.

18. If a No. 10 wire has a diameter of about $\frac{1}{10}$th of an inch what would be the cross-sectional area of a No. 19 wire?

19. How do you account for the capacity effect which is present on transmission lines?

20. What is the principal advantage of multiple-wire systems?

21. How can the self-induction on a transmission line be reduced?

22. Mention uses to which the series system is applicable.

23. Which is preferable for long distance transmission, three-phase or two-phase? Explain why.

INDEX

The page numbers of this volume will be found at the bottom of the pages; the numbers at the top refer only to the section.

Page

A

- Accumulators, depreciation of 289
- Acid spray 293
- Air-cooled transformer 164
- All-day efficiency 368
- Alternating-current circuits, measurement of power in 88
- Alternating-current lines, calculation of 353
- Alternating-current motors 54
  - polyphase induction 57
  - polyphase synchronous 56
  - single-phase synchronous 55
- Alternating-current plants 33
- Alternating-current systems of distribution 345
- Alternators in parallel 42
- Alternators in series 47
- Ammeter 80
- Annunciator wire 333
- Assembling of machine 23

B

- Balance of armature 66
- Battery room 278
- Belting 16
  - arrangement of 20
  - care of 20
  - double 18
  - lacing of 19
  - perforated 20
  - power of 17
  - width formula 18
- Bijur high duty battery 263
- Boiler foundations 146
- Boiler trials 251–256
  - laying out the curves 251

Note.—For page numbers see foot of pages.

Page

- Boiler trials
  - log of test, table 252
  - plotting the curves 252
- Boilers 134
  - Cornish and Lancashire 135
  - economic 136
  - marine 135
  - multitubular 135
  - water-tube 135
- Booster methods of regulation 317
  - compound booster 320
  - constant-current booster 322
  - differential booster 321
  - external control 323
  - series booster 319
  - shunt booster 318
- Buckling 291

C

- Cables 394
- Cadmium test 284
- Central station design 235–248
- Central station engineering 205–233
  - alternating-current systems 213
  - Brush arc system 206
  - consolidation of plants 223
  - Edison constant-potential system 206
  - Edison tube system 207
  - high-voltage polyphase systems 225
  - storage battery function 222
  - three-wire D. C. system 208
  - water powers 217
- Charging storage battery 282
- Chloride battery 269
- Compensators, starting 58
- Compound direct-current dynamo 33

Page

- Compound dynamos in parallel 40
- Compound-wound motor 52
- Conductors 327
  - capacity of for carrying current 331
  - effects of resistance in 331
  - insulation 332
  - material used 327
  - resistance of 328
- Constant-potential D. C. circuits 48
  - alternating-current motors 54
  - compound-wound motor 52
  - differentially-wound motor 52
  - dynamotors 54
  - series-wound motor 50
  - shunt-wound motor 48
- Copper 328
  - Matthiessen's standard 330
  - mechanical strength 330
  - temperature coefficient 330
  - weight 330
- Cornish and Lancashire boiler 135
- Cross-arms 380
- Current, measurement of 80
- Curtis steam turbine 151
- Cut-outs 28

D

- Differentially-wound motor 52
- Direct connection of engine and generator 15
- Direct-current dynamos in parallel 38
- Direct-current feeder panels 174
- Direct-current motors, starting boxes 30
- Disintegration 291
- Double belting 18
- Draft 147
- Dynamo-electric machinery 11–125
  - assembling of machine 23
  - circuits 31
  - connections, diagrams of 32–47
  - inspecting and testing 64
    - adjustment 64
    - balance 66
    - friction 64
    - heating 66
    - noise 66
    - sparking 67
  - mechanical conditions 12

Page

- Dynamo-electric machinery
  - rotation 34
  - running 61
  - selection of machine 11
  - switches 26
  - troubles (see "Troubles") 92–125
  - wiring 24
- Dynamos
  - compound direct-current 33
  - series 33
  - shunt 32
- Dynamotors 54

E

- E. P. S. battery 266
- Earthenware conduits 391
- Economic boiler 136
- Edison Companies 209
- Edison storage battery 276
- Efficiency 85
  - of storage batteries 288
  - of a transformer 368
- Electrical plant 160
  - exciters 163
  - gas engines 158
  - generators 160
  - safety devices 183
  - storage batteries 168
  - substations 185
  - switchboards 168
  - transformers 164
- Electrical resistance 71
  - insulation 75
  - metallic 71
- Electrolyte 259, 281
  - purity of 293
- Electro-magnetic circuit breakers 29
- Equalizer 39
- Exciter panels 174
- Exciters 163
- Exide battery 267

F

- Faure storage battery 266
- Feed water 144
- Feeding appliances 144
- Friction 64

Note.—For page numbers see foot of pages.

Page

G

- Galvanometers 78
- Gas engines 158
- Generating station, location of 128
- Generators 160
  - direction of rotation 34
  - directions for running 61
  - efficiency of 85
  - foundation for 12
  - location of 12
  - mechanical connections 14
  - in parallel 38
  - power of 84
  - selection of 11
  - separation of losses 86
  - in series 45
  - starting 36
  - stopping 63
  - torque of 84
- Gould storage battery 262
- Gutta percha 334

H

- Hydraulic plants 153
  - governors 158
  - water turbines 154

I

- Indicating wattmeter 88
- India rubber 334
- Inductance 351
- Induction motors
  - single-phase 60
  - speed regulation of 59
  - starting 57
- Insulation resistance 75
  - direct-deflection test 75
  - voltmeter test 76
- Insulators 381
- Iron or core losses 368

K

- Knife switches 26

L

- Lead storage batteries, chemical action in 261
- Lightning arrester 183
- Limit switches 29
- Lithanode 274
- Loss in pressure in steam pipes, formula for 142

M

- Machine
  - assembling of 23
  - direction of rotation 34
  - examination before starting 36
  - selection of 11
  - speed of 82
  - voltage of 78
- Manholes 392
- Marine boilers 135
- Mechanical connections 14
  - belting 16
  - direct 15
  - rope driving 20
  - toothed gearing 22
- Mechanical draft 147
- Mechanical strength of copper 330
- Metallic resistance 71
  - drop method test 73
  - Wheatstone bridge test 71
- Motors
  - alternating-current 54
  - compound-wound 52
  - differentially-wound 52
  - direction of rotation 34
  - directions for running 61
  - efficiency of 85
  - foundation for 12
  - induction 57
  - location of 12
  - mechanical connections 14
  - power of 84
  - selection of 11
  - separation of losses 86
  - series-wound 50
  - shunt-wound 48
  - stopping 63
  - torque of 83
- Multiple-wire systems of distribution 342
- Multitubular boiler 135
- Mutual-inductance 352

N

- Natural draft 147

Note.—For page numbers see foot of pages.

Page

O

- Oil-cooled transformer 165
- Oil switches 176
- Overhead lines 374
  - cross-arms 380
  - insulators 381
  - location of 375
  - pins 383
  - stresses sustained 384
  - supports 376

P

- Panels 170
  - direct-current feeder 174
  - exciter 174
  - total output 174
- Parallel systems of distribution 337
- Perforated belts 20
- Personal safety 62
- Planté storage battery 260
- Polyphase induction motor 57
- Polyphase synchronous motor 56
- Portable storage batteries 296
- Power factor 357
- Power stations 127–202
  - buildings 189
  - charging for power 201
  - electrical plant 160
  - generating station, location of 128
  - hydraulic plants 153
  - size of plant 132
  - station arrangement 194
  - station records 196
  - steam plant 134
  - substations, location of 129
  - system, selection of 130
- Power transmission 327–398
  - conductors 327
  - distribution systems 335
    - feeding point 339
    - multiple-series 341
    - multiple-wire 342
    - parallel 337, 345
    - polyphase 346
    - series 335, 345
    - series-multiple 341
  - overhead lines 374

Note.—For page numbers see foot of pages.

Page

- Power transmission
  - transformers 367
  - transmission lines 348
  - underground construction 387
- Primary cell 259

R

- Regulation of generator 316
  - booster methods of 317
- Resistance of electrical conductors, formula for 328
- Rope driving 20
- Rotor 57

S

- Safety fuses 28
  - enclosed or cartridge 28
  - open or link 28
- Series booster 319
- Series dynamo 33
- Series systems of distribution 335
- Series-wound direct-current dynamos in series 46
- Series-wound dynamos in parallel 39
- Series-wound motor 50
- Shafting 22
- Short-circuiting 292
- Shunt booster 318
- Shunt dynamo 32
  - in series 46
- Shunt-wound motor 48
- Single-phase induction motor 60
- Single-phase synchronous motor 55
- Sparking at commutator 67, 94
- Speed, measurement of 82
- Speed regulation of induction motors 59
- Starting-boxes 30
- Stator 57
- Steam engines 149
- Steam piping 137
  - arrangement 138
  - loss in pressure in, formula 142
  - material 140
- Steam plant 134
  - boiler foundations 146
  - boilers, see "Boilers" 134
  - draft 147

Page

- Steam plant
  - feed water 144
  - feeding appliances 144
  - firing of boilers 147
  - piping 137
  - steam engine 149
  - steam turbine 150
- Steam turbines 150
  - Curtis 151
- Storage batteries 168, 259–324
  - connection of 313
  - Edison 276
  - efficiency of 288
  - Faure type 266
    - E. P. S. 266
    - exide 267
  - function of 222
  - general principles of 261
  - management of 278
    - battery room 278
    - charging 282
    - discharging 287
    - electrolyte 281
    - setting up cells 278
  - portable 296
  - putting out of commission 295
  - Planté and Faure types 269
    - chloride 269
    - lithanode 274
    - tudor cell 273
  - Planté type 260
    - Bijur high-duty 263
    - Gould 262
  - regulation of 315
  - tests 294
    - for chlorine 294
    - for copper 294
    - for ferric salts 294
    - for iron 294
    - for mercury 295
    - for nitric acid 294
  - troubles and remedies 290
    - acid spray 293
    - buckling 291
    - disintegration 291
    - purity of electrolyte 293
    - short-circuiting 292

Page

- Storage batteries
  - troubles and remedies
    - sulphating 290
  - various uses of 298–312
  - Waddell-Entz 275
- Substations, location of 129
- Sulphating 290
- Superheated steam 143
- Switchboards 168
- Switches 26
  - oil 176
- Synchronism 43

T

- Tables
  - aluminum wire, resistance of 329
  - Bijur high-duty battery data 264
  - boiler efficiencies 137
  - boiler efficiency, increase in 144
  - boiler floor space 136
  - capacity ratios 187
  - capacity variation data 288
  - chloride battery data 272
  - circuit capacity data 340
  - conductors for various conditions 331
  - conductors for various positions 332
  - copper wire 328
  - copper wires, safe carrying capacity of 25
  - E. P. S. accumulator data 267
  - efficiencies, average maximum 162
  - exide cells, data 269
  - exciters for single-phase A. C. generators 163
  - full load ratios 187
  - horse-power per cu. ft. of water, etc. 158
  - inductance per mile of 3-phase circuit 350
  - log of test 252
  - machine for various kinds of circuits 31
  - permissible overload 33 per cent 133
  - riveted hydraulic pipe 156
  - shafting 22
  - specific gravity of dilute sulphuric acid at various temperatures 295
  - steam engine data 150
  - switch data 27
  - temperature effects in spans 386
  - transmission lines data 355

Note.—For page numbers see foot of pages.

	Page
Tables	
tudor cells	273
underground cable construction	396
water flow data	146
water pressure	155
wire and cable, standard	171
Tachometer	82
Temperature coefficient	330
Temperature rise in electrical apparatus	66
Toothed gearing	22
Torque, measurement of	83
Total output panels	175
Transformers	164, 367
air-cooled	164
connections	370
efficiency of	368
frequency	373
losses of power in	368
oil-cooled	164
regulation of	369
water-cooled	166
Transmission lines	348
capacity	348
inductance	351
Troubles	93–125
dynamo fails to generate	118
heating of armature	105
heating of bearings	107
heating of commutator and brushes	103
heating of field magnets	106
motor stops or fails to start	115
noisy operation	110
sparking at commutator	94
speed too high	114
speed too low	114
voltage of generator not right	124
Tudor cell	273

Note.—For page numbers see foot of pages.

	Page
Turbines	
steam	150
water	154

U

Underground construction	387
cables	394
Crompton system	389
earthenware conduits	391
manholes	392
protection of circuits	397
Siemens-Halske system	389
trench system	389
voltage to be used	396
wrought-iron pipes	390
Underwriter's wire	333

V

Voltage, measurement of	78
Voltmeter test for insulation resistance	76

W

Waddell-Entz accumulator	275
Water-cooled transformer	166
Water powers, development of	217
Water-tube boilers	135
Water turbines	154
Weatherproof wire	333
Weight of copper	330
Wheatstone bridge	71
Wire	333
annunciator	333
underwriter's	333
weatherproof	333
Wiring dynamo-electric machinery	24
Wiring formula	354